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Adjusting Potential to Actual Evapotranspiration Rates Applicable over Large Spatial Regions

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ADJUSTING POTENTIAL TO ACTUAL EVAPOTRANSPIRATION RATES
APPLICABLE OVER LARGE SPATIAL REGIONS

by

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ADJUSTING POTENTIAL TO ACTUAL EVAPOTRANSPIRATION RATES APPLICABLE OVER LARGE SPATIAL REGIONS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

With the advent of the petroleum shortages of the mid 1970's, American society became aware of the need for wise management of all our natural resources. In a predominantly agricultural state, such as South Dakota, management of soil and water resources are of prime importance. Thus, there is the need to be able to monitor those kinds of resources over a large spatial region yet for a minimum of cost and effort.

Specifically, soil moisture estimates are important inputs into many agricultural resource models. Estimating crop yield, runoff, and infiltration; as well as predicting agricultural crop diseases; and even monitoring desertification are just a few examples of the different types of resource models that use soil moisture as an input parameter. Currently soil moisture conditions are determined using ground truth observations. However, this method is impractical and expensive for use in predicting moisture conditions over a large area on a regular basis.

Because of their repetitive flight patterns and broad spatial coverage, satellites hold great promise for supplying the data necessary to predict soil moisture conditions. Already satellite data have been used to predict such input parameters to soil moisture models as solar radiation values and leaf area indices. In addition, surface soil moisture or rainfall events could be detected remotely and used as model inputs. Conceivably, satellite imagery could be used to predict most, if not all, of the inputs into a soil moisture model.

Although the use of satellite data sounds like a timely panacea, there are some inherent questions to be answered first. Of importance is the question of whether existing soil moisture models (which heretofore have been used locally) can be applied or adjusted to regional use. Hence, this study was initiated with the purpose of determining if current soil moisture theory can be adjusted to large area use.

Since there are many different approaches to predicting soil moisture, this study was limited to the water balance approach. In this method, total soil moisture is the difference between the total water into the system (precipitation or irrigation) and the total water out of the system. The outgoing water can be in the form of transpiration through the plant canopy or evaporation from the soil surface. Evapotranspiration equations attempt to model these two processes simultaneously as one water loss value. This combined process, referred to as evapotranspiration, is dependent upon climatic variables, such as solar radiation, air temperature; and vegetative variables, such as canopy type and leaf area index. In general, the evapotranspiration equations are derived under theoretical conditions and produce a potential or maximum value as a result. Therefore, empirical crop coefficients called k-values are derived from field data to adjust the potential value to an actual one. By using the water balance approach, the k-values used to calculate an actual evapotranspiration rate must be derived for large spatial areas before soil moisture prediction over these broad areas is possible. Furthermore, the effects of diverse differences in soil type, soil moisture contents, and crop variety on these crop coefficients need to be studied. In other words, the parameters controlling or affecting the coefficients need to be understood before large scale prediction of evapotranspiration and subsequently soil moisture is possible.

In an attempt to understand the crop coefficients and their adjustment to large areas, this study was designed with the following objectives:

1. Derive crop coefficients from actual soil moisture data to adjust potential evapotranspiration rates to actual evapotranspiration rates over a broad spatial region (state of South Dakota).
2. Determine what measurable variables significantly affect the crop coefficients.
3. Determine an equation to predict crop coefficients from measurable parameters such that spatial and temporal effects are negligible (i.e. adjust the coefficients for broad area, year after year use).

LITERATURE REVIEW

Background

The purpose of soil moisture modeling is to monitor the incoming and outgoing water of a system and determine the resulting total moisture content or moisture profile within the soil. This process can be very complicated as there are many factors which affect the moisture content of the soil. In his review of soil moisture modeling, Hildreth (1978) suggests that there are seven factors which can affect the amount of soil moisture present at any given time. According to Hildreth, precipitation (or irrigation), surface runoff, net subsurface lateral movement, evaporation, transpiration, capillary rise from lower levels, and lower level drainage all affect the water content of a soil profile. Figure 1 depicts the relationships of each of these parameters to the soil profile.

Although all seven factors do contribute to the soil moisture content, many of them are negligible and therefore do not need to be considered in the modeling process. Hildreth (1978) states further that both surface runoff and subsurface lateral movement can be neglected since most agricultural fields tend to be nearly level. Evaporation and transpiration account for most of the water lost from the profile. Baier (1967) contends that about 70% of the rainfall on the land surface is lost through evaporation from the soil or by transpiration through plants. Therefore, water lost through drainage can be considered

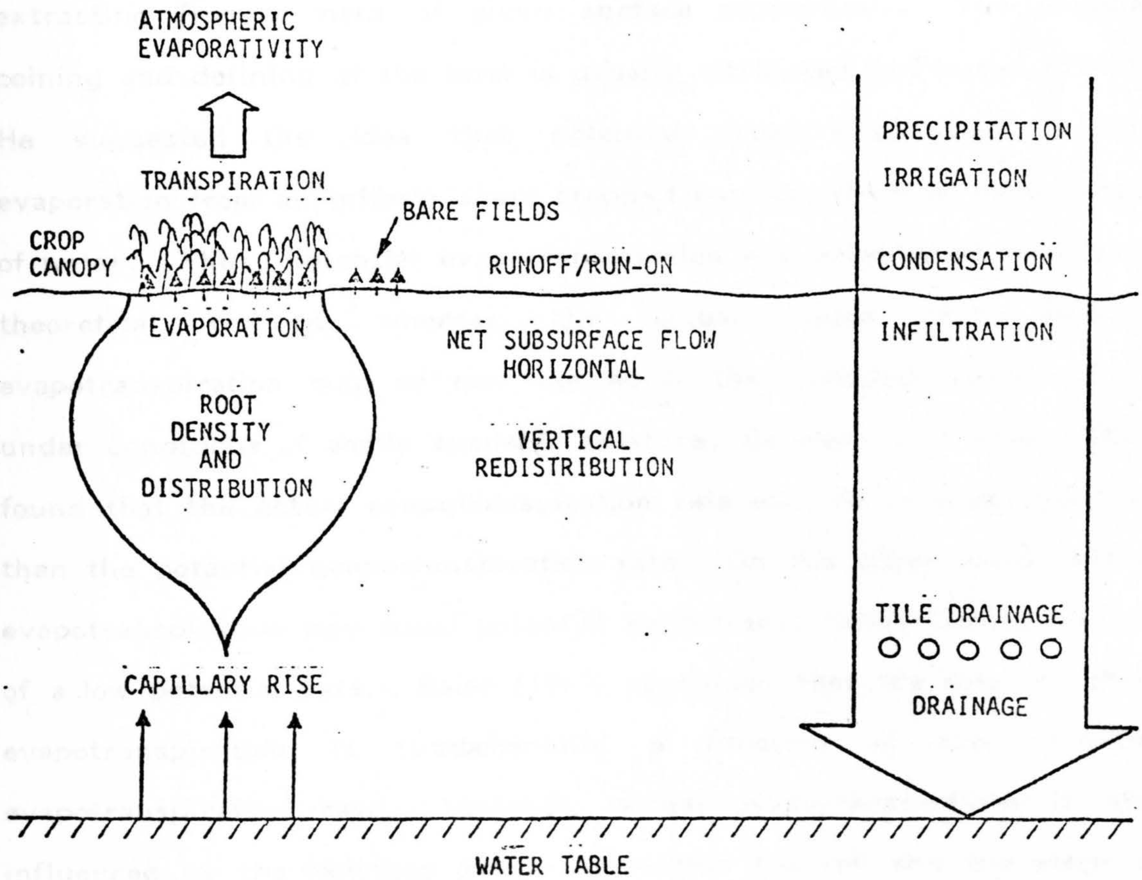


Figure 1: Water Balance Components in a Soil Profile.

negligible compared to the water lost through the evapotranspiration process.

Hillel (1971) defines the concept of potential evapotranspiration as the "maximum evaporation rate which the atmosphere is capable of extracting from a field of given surface properties". The original coining and defining of the term is usually attributed to Penman (1948). He suggested the idea that potential evapotranspiration is the evaporation from an infinite short cropped surface which is never short of water. Thus, potential evapotranspiration was established more as a theoretical concept whereas the actual water lost through evapotranspiration may or may not equal the potential value. Even under conditions of ample available moisture, Denmead and Shaw (1962) found that the actual evapotranspiration rate may be considerably less than the potential evapotranspiration rate. On the other hand, actual evapotranspiration may equal potential evapotranspiration during periods of a low potential rate. Baier (1967) concluded that the rate of actual evapotranspiration is fundamentally a function of the potential evapotranspiration rate. However, actual evapotranspiration is also influenced by the moisture availability within the soil and the stage of crop canopy development. Several models employ a plant factor for calculating the actual evapotranspiration from the potential. These plant factors vary with crop variety and development stage. Criddle (1958) suggests that actual evapotranspiration rates differ due to improved fertilization and other management practices. However, the primary factor affecting the crop coefficient appears to be the type of crop and its growth stage. Again according to Criddle (1958), the "close-growing" crops have very similiar coefficients while there is much variation between coefficients for citrus orchards, rice, or bananas. Blaney (1959) reported seasonal crop coefficients for alfalfa from 0.80 to 0.85, and for small grains from 0.75 to 0.85. In his evaporation model, Ritchie (1972) adjusts the potential evaporation rate with a negative exponential function of leaf area index. Kanemasu et. al. (1976) uses this same crop factor in his model to calculate actual evaporation and transpiration rates. Furthermore, Baier (1971) found that the actual evapotranspiration conversion factor was related to the percentage of crop cover and subsequently changed during the growing season. Ritchie (1972) cites an attempt by Jensen (1970) to modify the plant factor to parallel changes in soil wetness as well.

Many methods have been proposed to estimate the potential evapotranspiration rate from climatic data. These formulas typically include some combination of the climatic factors of temperature, solar radiation, humidity, and wind. They range from the simplistic method of Thorthwaite (1948), who used mean air temperature and day length to calculate potential evapotranspiration, to the theoretical work of Penman (1948) and more recently Priestley and Taylor (1972). Likewise, other potential evapotranspiration equations rely heavily on empirical constants derived for a specific locale and crop cover.

To effectively utilize satellite data, a potential evapotranspiration equation is needed that uses climatic variables predictable by satellite (such as solar radiation). Moreover, the potential evapotranspiration equation must have enough physical basis to make it applicable to broad spatial regions. Baier and Robertson (1965) found that the correlations between maximum temperature, minimum temperature, and solar radiation with evaporation were highly significant. Stephens (1965) reported that wind speed had little effect on evaporation rates once the speed reached a threshold value of 2.24 mph. He also reported that overestimation of the wind speed by 100% resulted in only a 10% overestimate of evaporation rate using the Penman formula (1943). Jensen and Haise (1963) accounted reasonable success in estimating evapotranspiration using data collected over a 35 year period to derive regression equations relating solar radiation and air temperature. In his paper, Stephens (1965) refined the Jensen-Haise approach by also considering the average relative humidity of the region. Priestley-Taylor (1972) related the evapotranspiration from a well-watered surface to net radiation and air temperature. Their equation was based on a surface energy balance approach. The Jensen-Haise and Priestley-Taylor approaches both lend themselves well to this study because of the availability of the necessary input parameters from satellite data and their applicability over large areas. Specific theory used to derive the Jensen-Haise and Priestley-Taylor formulas follows in the Theory section.

As stated earlier, for a potential evapotranspiration equation to be applicable over a broad area it must be fundamentally based on sound physical theory. If the physical processes causing the evapotranspiration are accounted for within the equation, then this equation should correctly apply to any region where evapotranspiration is occurring. The actual evapotranspiration rate can then be calculated using coefficients (such as the plant factors previously mentioned) derived for the conditions within that certain region.

Theory

Priestley-Taylor Equation

The Priestley-Taylor Equation was derived by considering the total energy balance at the soil surface. Direct solar radiation is the major component of all incoming energy striking the earth's surface. Since the atmosphere absorbs and scatters some of the solar radiation, only part of it finally reaches the ground. However, part of this scattered radiation (called diffuse solar radiation) does eventually reach the ground. Thus, the total incoming energy at the soil surface is made up of both direct solar and diffuse solar radiation. Daily totals of the direct solar radiation on a cloud-free day during the summer range from 500-700 langleys/day (Monteith, 1975). Outgoing radiation is in the form of both reflected and emitted radiation from the earth's surface. Net radiation is the overall difference between the total incoming and the total outgoing radiation. This radiation balance is shown in Figure 2.

Net radiation is the energy that is available for heating the soils, plants, and atmosphere; for carrying on photosynthesis; and for driving the process of evapotranspiration. The energy balance equation for the advection-free situation can be written as:

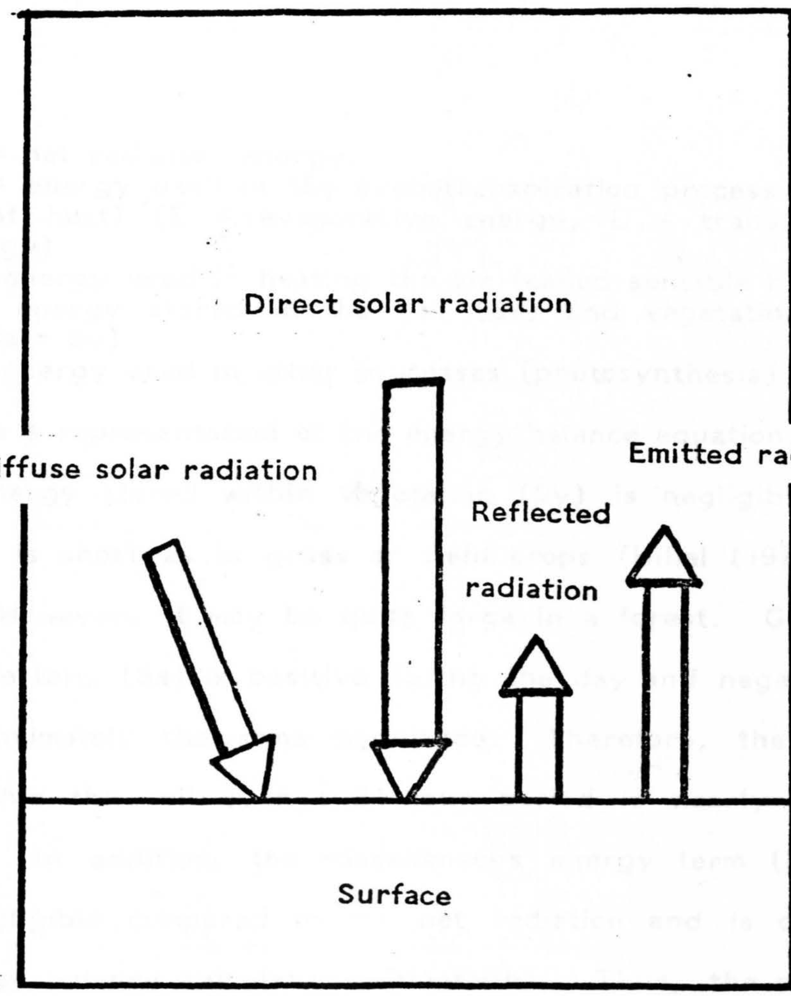


Figure 2: The Radiation Balance at the Soil Surface.

$$Rn = LE + H + S + M \tag{1}$$

where,

Rn = net radiation energy.
LE = energy used in the evapotranspiration process (called latent heat) (E = evaporative energy, L = transpirative energy)
H = energy used in heating the air (called sensible heat)
S = energy stored in the soil (Ss) and vegetation (Sv) (S=Ss + Sv)
M = energy used in other processes (photosynthesis)

Figure 3 is a representation of the energy balance equation.

Energy stored within vegetation (Sv) is negligible where the vegetation is short as in grass or field crops (Hillel (1971), Monteith (1975)). However, it may be quite large in a forest. Generally, the soil storage term (Ss) is positive during the day and negative at night with approximately the same magnitude. Therefore, the net energy stored within the soil over a 24-hour period is nearly zero (Hillel, Motheith). In addition, the miscellaneous energy term (M) is almost always negligible compared to the net radiation and is often omitted from energy balance calculations (Monteith). Thus, the major portion of the total daily net radiation goes into latent and sensible heat (LE and H terms). Table 1 (from Monteith) gives representative values for each of the balance components over a vegetated surface for cloudless, summer conditions.

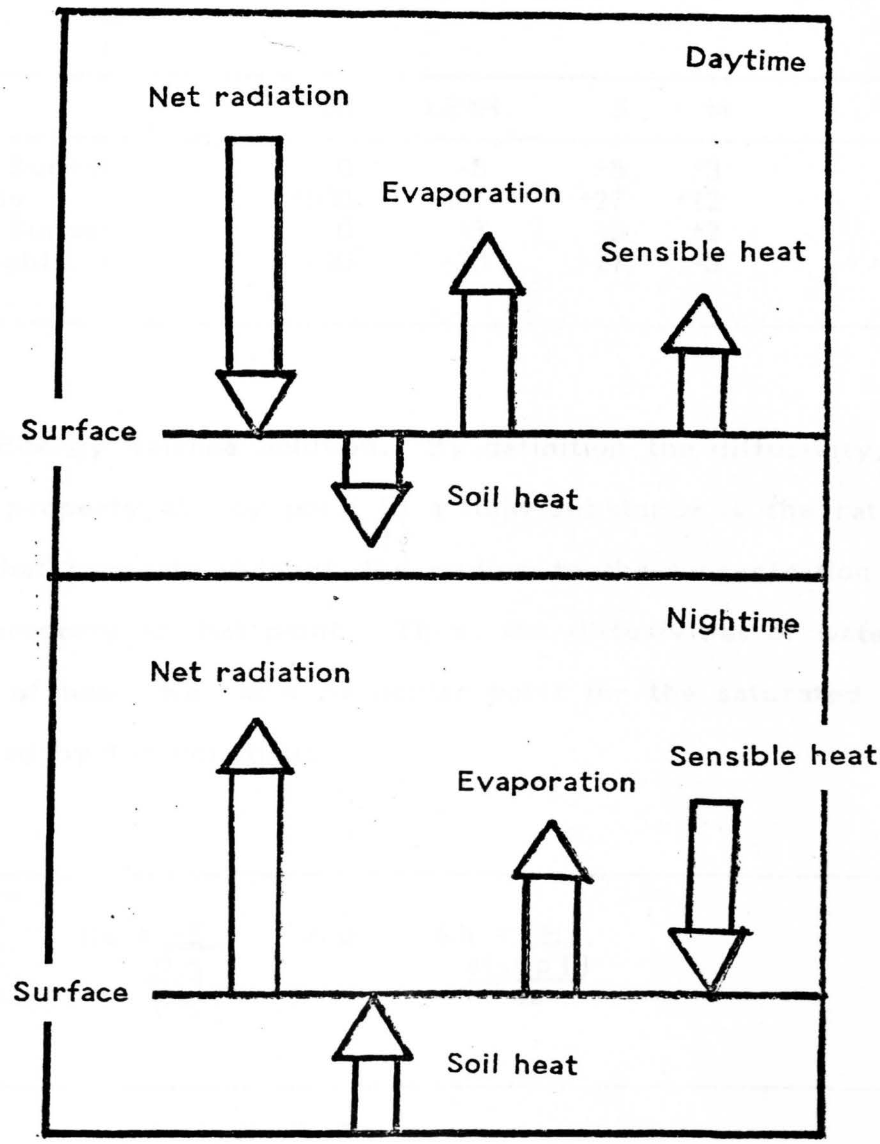


Figure 3: The Energy Balance at the Soil Surface.

TABLE 1

Typical Energy Budget over Vegetation (W/M^2)

	Rn	LE+H	S	M
Near Sunrise	0	-8	+5	+3
Midday	+500	+461	+27	+12
Near Sunset	0	+3	-5	+2
Midnight	-50	-20	-27	-3

Energy Balance Solution. By definition the diffusivity, K, of a physical property at any point in a fluid substance is the ratio of the flux of that property through the medium to the concentration gradient of that property at that point. Thus, the diffusivities of water vapor, Kv, and of heat, Kh, at a particular point for the saturated condition are defined by the equations:

$$Kv = \frac{-E}{\left(\frac{\partial x}{\partial z}\right)} \quad \text{and} \quad Kh = \frac{-H}{\frac{\partial(\rho CpT)}{\partial z}} \qquad (2)$$

where,

E = evaporation flux
H = sensible heat flux
z = height of point considered
χ = water vapor concentration (absolute humidity)
ρCpT = sensible heat concentration (ρ = density of air, Cp = specific heat of air, T = air temperature)

Absolute humidity can be defined as:

$$\chi = \rho q \tag{3}$$

where,

q = specific humidity (gram of water vapor per gram of air)

Specific humidity can be expressed as:

$$q = \frac{\varepsilon e}{P} \tag{4}$$

where,

e = vapor pressure
ε = ratio of molecular weight of water to the mean dry weight of air (5/8)
P = total pressure

Thus,

$$\chi = \frac{\rho\varepsilon\ e}{P} \tag{5}$$

The thermodynamic value of the psychometric constant, γ, is defined as:

$$\gamma = \frac{CpP}{L\varepsilon} \tag{6}$$

where,

L = latent heat of vaporization of liquid water (transpirative energy)
γ =.66 mbar/°C at atmospheric pressure

Therefore,

$$\chi = \frac{\rho Cpe}{L\gamma} \tag{7}$$

According to Monteith (1975), vapor pressure (e) and temperature (T) vary significantly with vertical changes in height (z). However variations of the other factors (ρ, Cp, γ, L) are small in comparison and can be neglected. The diffusivities can finally be expressed as:

$$Kv = \frac{-E}{\left(\frac{\rho Cp}{L\gamma}\right)\left(\frac{\partial e}{\partial z}\right)} \quad \text{and} \quad Kh = \frac{-H}{(\rho Cp)\left(\frac{\partial T}{\partial z}\right)} \tag{8}$$

Solving for the latent heat (LE) and sensible heat (H) terms yields:

$$LE = -Kv \left(\frac{\rho Cp}{\gamma}\right)\left(\frac{\partial e}{\partial z}\right) \text{and } H = -Kh\ (\rho Cp)\frac{\partial T}{\partial z} \tag{9}$$

The similarity hypothesis (Monteith) states that Kv = Kh. Solving for LE/H gives:

$$\frac{LE}{H} = \left(\frac{1}{\gamma}\right)\left(\frac{\partial e}{\partial T}\right) \tag{10}$$

Define the quantity **s** as:

$$s = \left(\frac{\partial e}{\partial T}\right) \tag{11}$$

Then,

$$\frac{LE}{H} = \frac{s}{\gamma} \tag{12}$$

The Bowen ratio (β) is defined as:

$$\beta = \frac{H}{LE} = \frac{\gamma}{s} \tag{13}$$

Finally, solving for the ratio LE/(LE + H) gives:

$$\frac{LE}{LE+H} = \frac{1}{1+\beta} = \frac{1}{1+\frac{\gamma}{s}} = \frac{s}{s+\gamma} \tag{14}$$

For convenience,

$$\frac{s}{s+\gamma} = Svp \tag{15}$$

Rearranging,

$$LE + H = \frac{LE}{Svp} \tag{16}$$

Recall from equation (1) that:

$$Rn = LE + H + S + M$$

As stated previously, S and M are negligible. Hence,

$$Rn = LE + H = \frac{LE}{Svp} \tag{17}$$

For the saturated situation, LE would be the maximum possible evapotranspiration rate E max).

$$E\ max = Rn(Svp) \tag{18}$$

Priestley and Taylor (1972) defined a term designated as "α" to account for the less than totally saturated situation. They expressed the potential evapotranspiration rate (PET) as:

$$PET = (\alpha Rn)(Svp) \tag{19}$$

where, $\alpha = 1$ at total saturation. Priestley and Taylor did considerable study on the α term and found that it varied with crop canopy. They suggested an overall mean α of 1.26. Many researchers have used the Priestley-Taylor formula in various studies of evapotranspiration (Tanner and Jury (1975), Kanemasu et. al. (1976)).

Jensen-Haise Equation

The Jensen-Haise equation was derived using many sets of data collected over a large number of years. The equation was tested on fields of alfalfa, cotton, oats, and wheat located in arid and semiarid areas (Jensen and Haise, 1963). This evapotranspiration equation was arrived at by considering potential evapotranspiration (PET) and solar radiation (Rs) as a function of average temperature (T) and doing a linear regression on numerous data points.

$$\frac{PET}{Rs} = aT + b \tag{20}$$

Although excellent correlation coefficients were obtained with the resulting equation (Jensen and Haise, 1963), its derivation had no physical theoretical basis. The Jensen and Haise equation was the result of a statistical procedure applied to actual data values. While intuitively one would expect a relationship between the cause of the process (solar radiation) and the process itself (evapotranspiration), derivation of the Jensen and Haise equation sheds no light on why evapotranspiration behaves in this fashion. On the other hand, the Jensen and Haise equation did correlate well with observed data and consequently may simulate the evapotranspiration process as realistically as a theoretically based equation.

DATA COLLECTION

Soil Moisture

Soil moisture data were collected throughout the state of South Dakota for the summers of 1979-1981. Gravimetric soil moisture profiles were taken at 6 inch increments down to a maximum depth of 4 feet. The samples were oven dried in portable microwave ovens, and moisture determined as a percentage of dry weight. Figure 4 and Figure 5 show the locations of the soil moisture sites within the state. During the 1979 sampling season there were 78 sites, while in 1980 there were 89. More sites were added in 1981, giving a total of 99 sites for that sampling interval. These additional sites were a result of the extra manpower due to the joint effort on this project between the Physics Department and the Remote Sensing Institute. Moisture sites were selected to encompass the major soil and cropping regions shown in Figure 6 and Figure 7.

Frequency of site visit was approximately every two weeks for the 1979 and 1980 collection periods, and every week for the 1981 period. The increased frequency in 1981 was also due to the extra manpower available through the joint effort. Table 2 lists the periods of data collection. The majority of the sites were in fields of pasture or small grain; however some corn and alfalfa plots were also sampled. A summary of sites by crop type is given in Table 3. Additionally, color slides were taken at each location. These slides were later

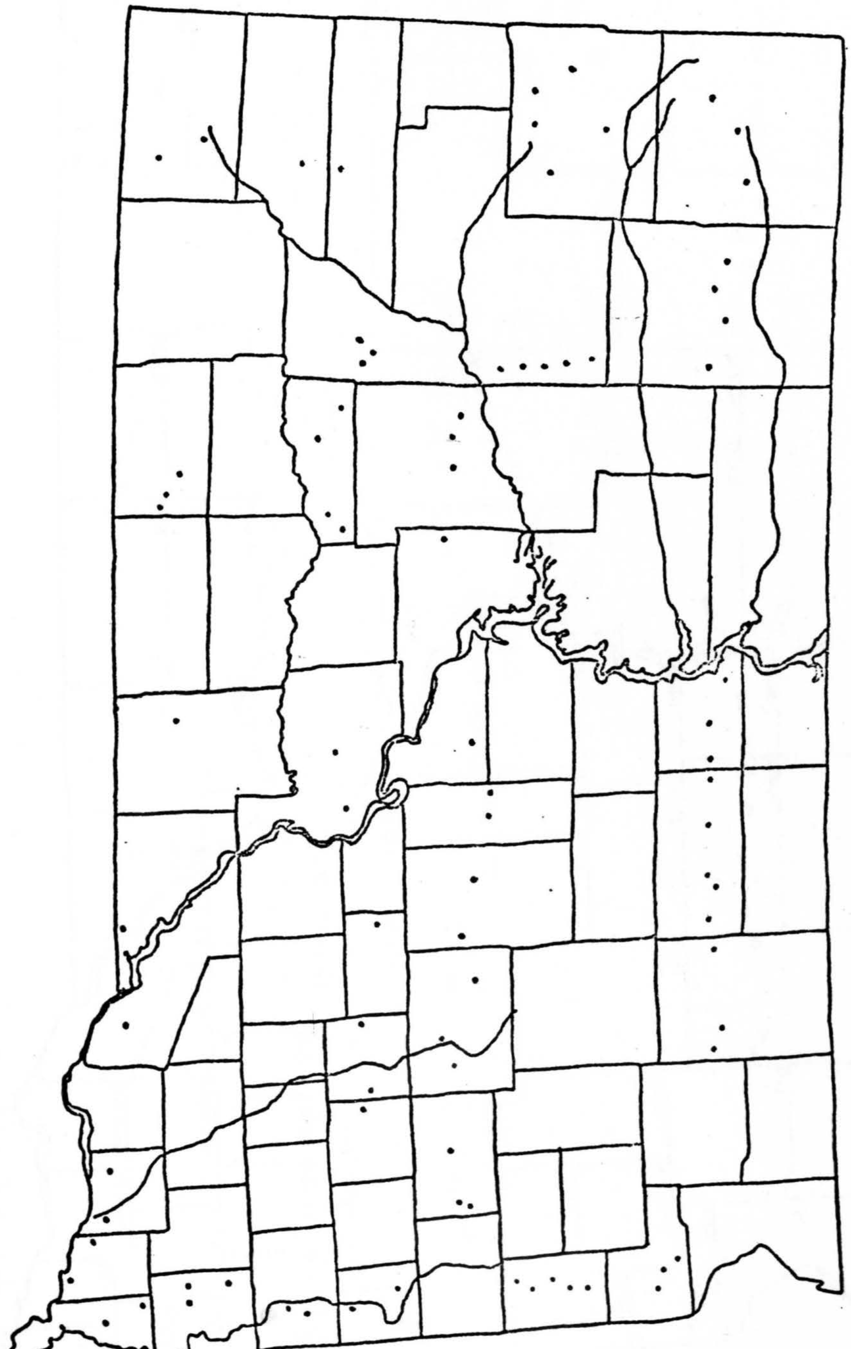


Figure 4: 1979-80 Soil Moisture Site Locations.

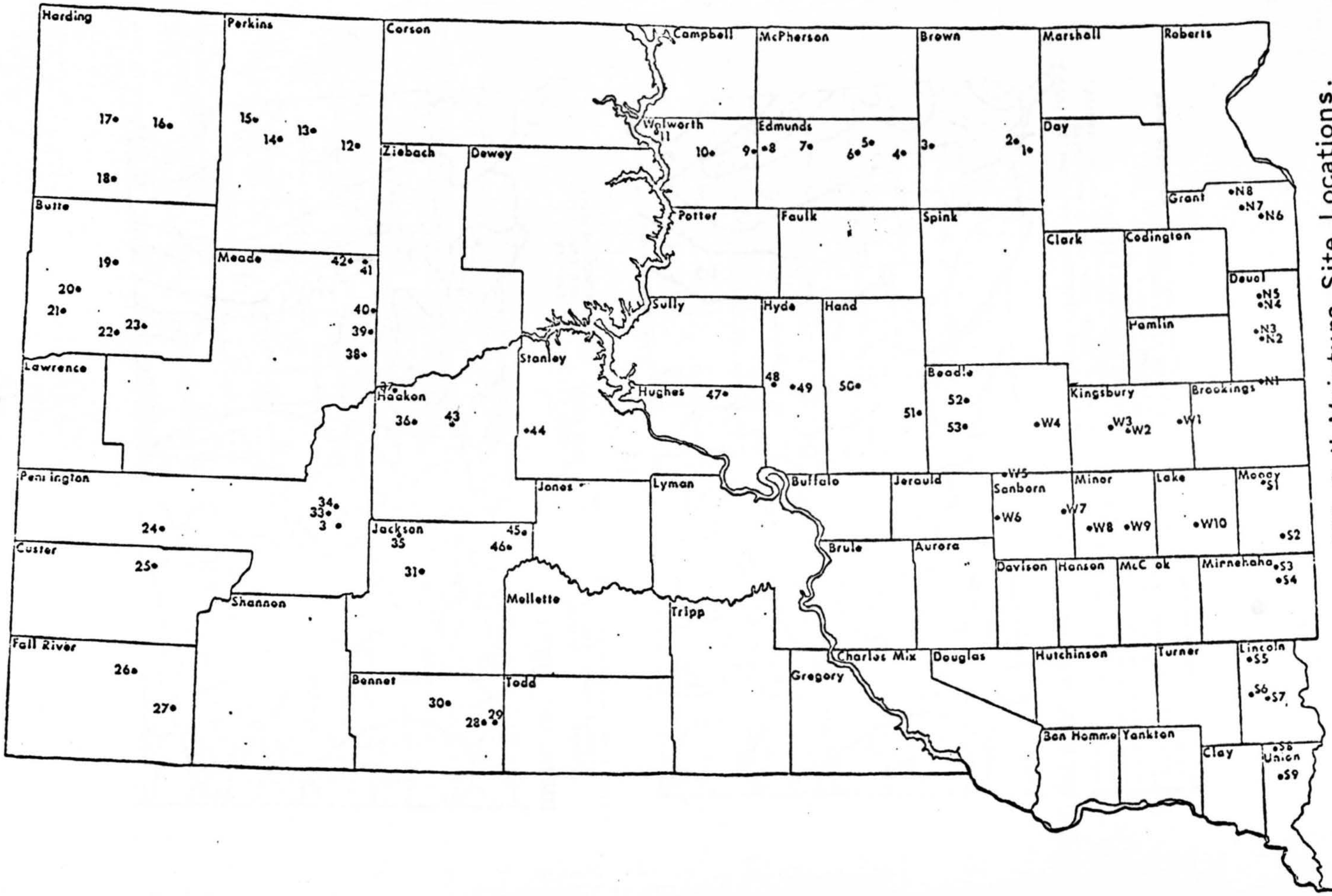
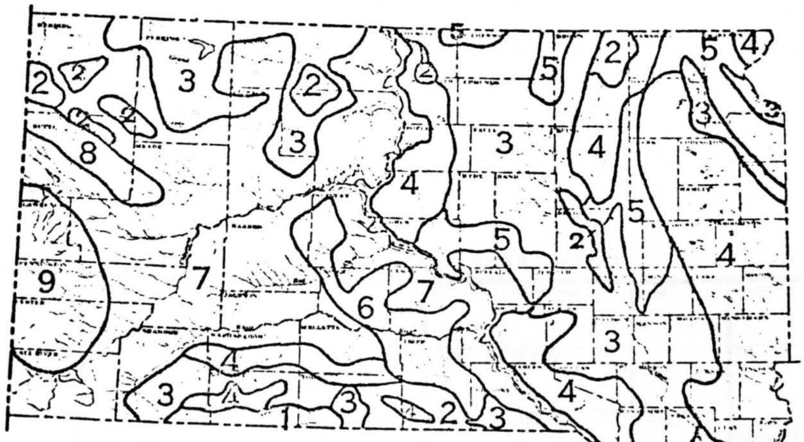


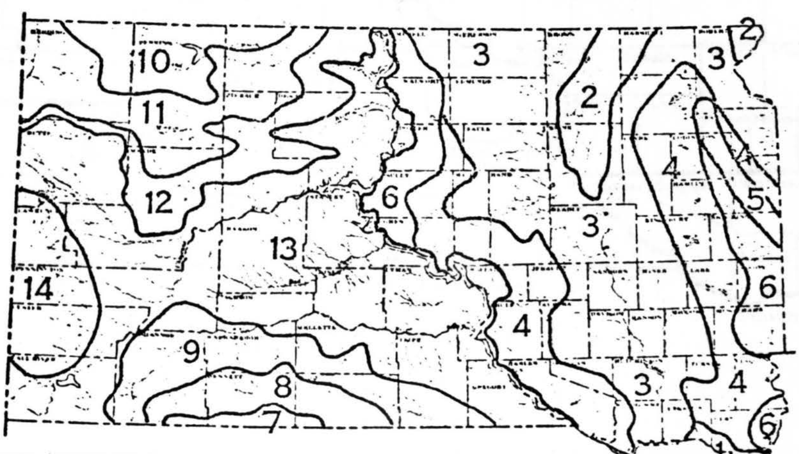
Figure 5: 1981 Soil Moisture Site Locations.



DOMINANT SOIL TEXTURES

1.SAND 3.LOAM 5.CLAY LOAM 7.FIRM CLAY
2.SANDY LOAM 4.SILT 6.FRIABLE CLAY 8.VERY FIRM CLAY
9.MAINLY BEDROCK

SDSU Plant Science Chart by F.C.Westin,



SOIL PARENT MATERIALS

1.ALLUVIUM
2.GLACIAL LAKE BASIN-SILTS, SAND
3.LATE WISCONSIN GLACIAL DRIFT-LOAM
4.LATE WISCONSIN GLACIAL DRIFT-SILTS
5.EARLY WISCONSIN GLACIAL DRIFT-SILTS
6.EARLY GLACIAL DRIFT-THICK SILTS
7.SAND HILLS
8.OLIGOCENE-ARICKAREE, SANDSTONE,SILTSTONE
9.WHITE RIVER BEDS, SILTS AND CLAYS
10.CANNONBALL-LUDLOW-FORT UNION, UNDIFF.
11.HELL CREEK-SANDY SHALES
12.FOX HILLS-SANDSTONE
13.PIERRE SHALE
14.BLACK HILLS UNDIFF.

SDSU Plant Science Chart by F.C.Westin,Based on SD Geologic Survey and USGS Maps

Figure 6: Soil Type Regions.

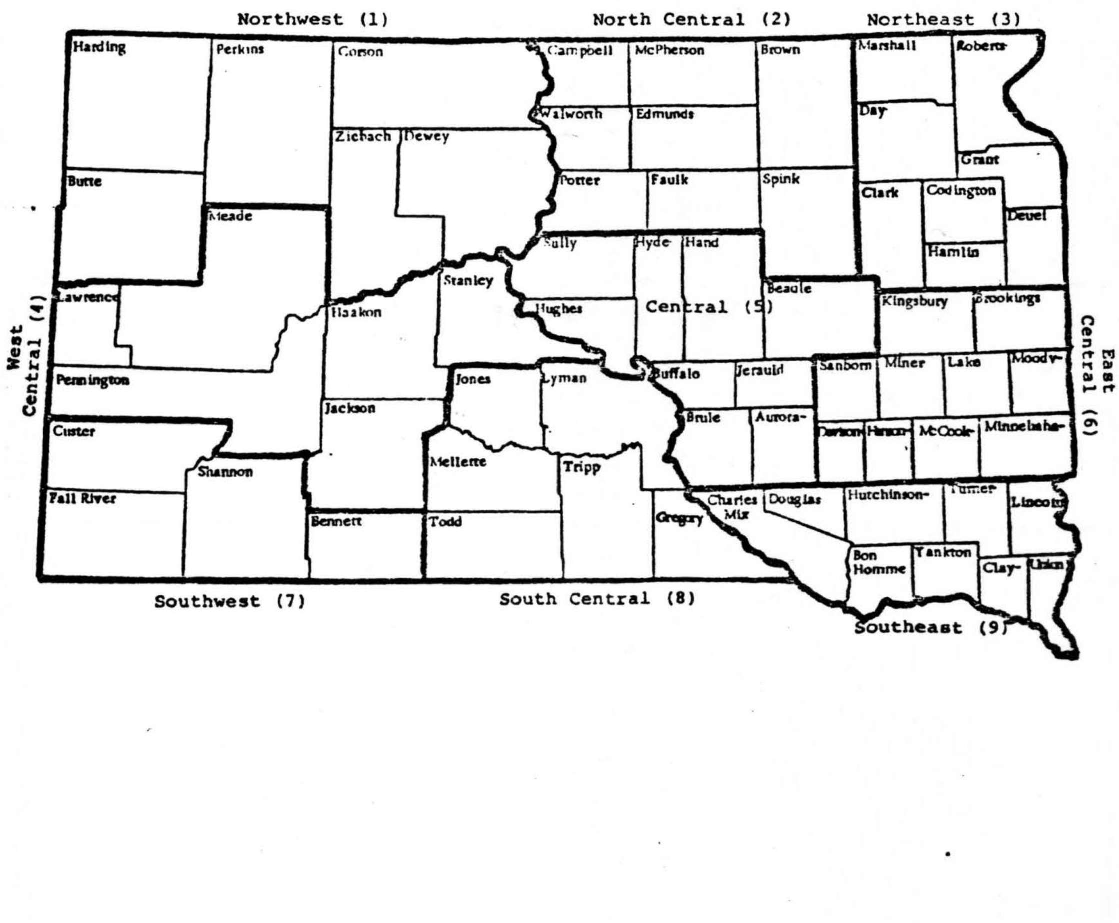


Figure 7: Cropping Regions.

projected on a random dot grid and percentage vegetation and percentage bare soil determined.

TABLE 2

Sampling Dates for the Soil Moisture Collection Sites.

1979 - 78 Sampling Sites		
June 25	-	July 2
July 10	-	July 14
July 23	-	July 27
Aug 3	-	Aug 10
Aug 13	-	Aug 16
Aug 21	-	Aug 23
1980 - 89 Sampling Sites		
June 16	-	June 20
July 7	-	July 11
July 21	-	July 25
Aug 7	-	Aug 11
Aug 21	-	Aug 25
1981 - 99 Sampling Sites		
June 1	-	June 3
June 9	-	June 11
June 16	-	June 18
June 23	-	June 25
June 30	-	July 2
July 6	-	July 8
July 13	-	July 15
July 20	-	July 22
July 27	-	July 29
Aug 4	-	Aug 6
Aug 11	-	Aug 13
Aug 18	-	Aug 20

TABLE 3

Crop Cover on the Soil Moisture Collection Sites.

Crop	Number of Sites 1979	1980	1981
Alfalfa	8	7	14
Pasture	42	68	58
Small Grain	28	14	23
Corn	0	0	4

The soil moisture data were entered into a computer data base and volumetric moisture contents were calculated. Because bedrock or hardpan is often encountered in South Dakota soils before the 4 foot depth, the last foot of soil data was often unavailable. Therefore, the profile to be considered was adjusted to a 3 foot depth. Any missing moisture percentages were then calculated as an average of the surrounding depths or an extrapolation of the last available depth.

Rainfall

Rainfall for the three summers under study was obtained from the South Dakota Department of Natural Resources. Approximately 1300 rain gauges are located at farmsteads within the state. Gauges are read each morning for the previous 24 hour total precipitation. The exact number of these precipitation recording sites varies by year due to differences in farmer participation. The basic network, however, is shown in Figure 8. Daily precipitation totals from each of the sites within the network for 1979-1981 were also encoded into the computer data base. Special care was taken to denote a zero rainfall amount from a missing rainfall amount. Monthly totals were also included.

Solar Radiation

South Dakota has only one National Weather Service station which routinely records solar radiation data. Therefore, it was decided to use satellite derived solar insolation values since state-wide coverage was needed. Tarpley (1979) showed that solar insolation can be estimated with reasonable accuracy using data from the Geostationary Operational Environmental Satellite (GOES). For cumulative daily totals, he calculated a correlation coefficient between ground pyranometer values and satellite values of $r = 0.7$ to $r = 0.9$. His standard error was less than 10% of the mean daily insolation for the year and better than 5% when only clear days were considered. These results were further substantiated by Brakke and Kanemasu (1981). Tarpley routinely uses the measurements from the visible channel of the GOES Visible and Infrared Spin Scan Radiometer (VISRR) in a regression equation to estimate the insolation values. These values are for 50-km targets centered at the intersections of 1° latitude and longitude lines, giving 45 sites within South Dakota.

Computer tapes of the insolation values were obtained from Dr. Tarpley at the National Oceanic and Atmospheric Administration in Washington, D.C. Estimates were available for June 25 - August 31

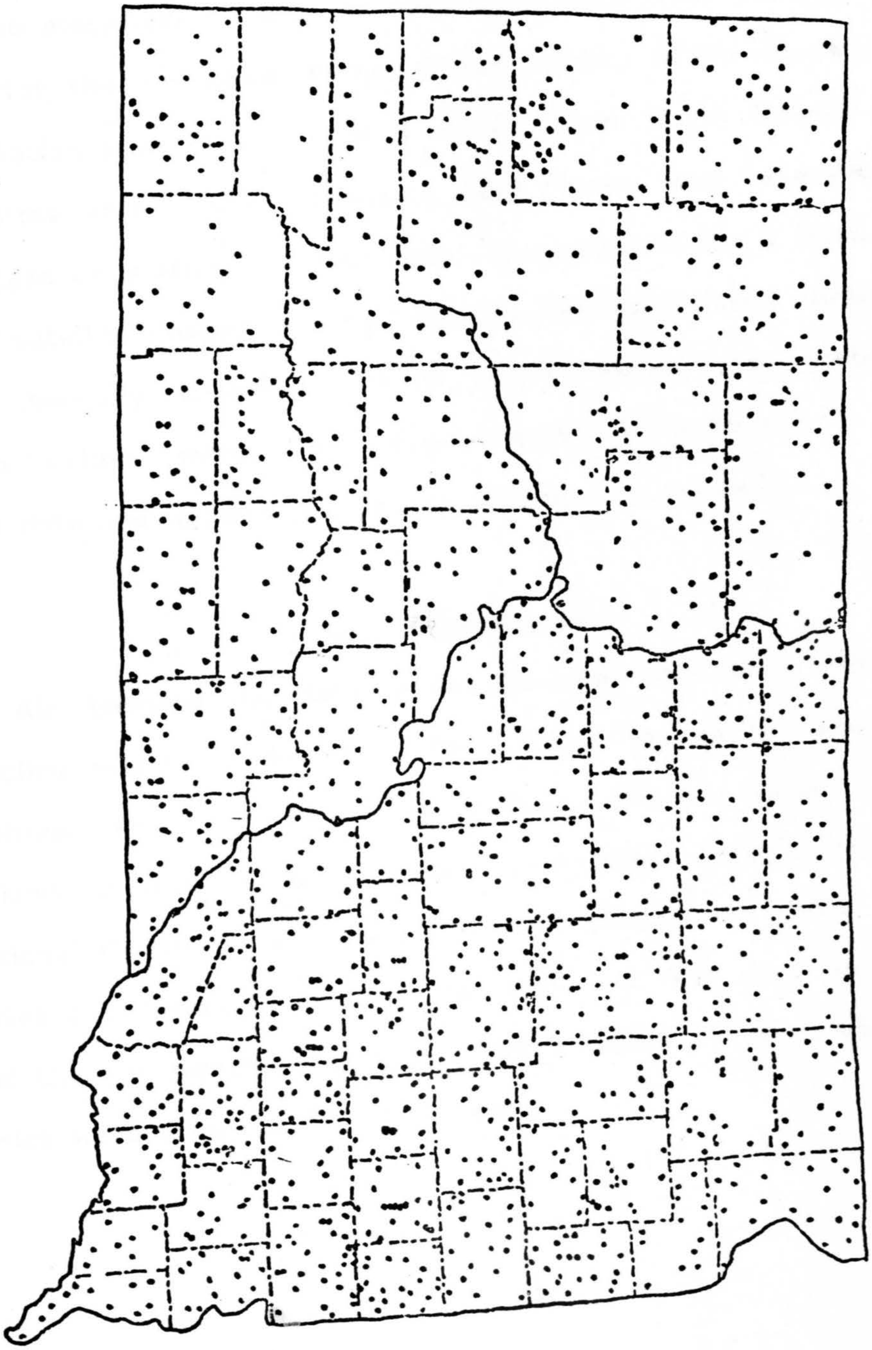


Figure 8: Rain Gauge Network 1979-81.

for 1980 and June 1-August 31 for 1981. Therefore, 1979 values had to be obtained elsewhere. Data for 1979 was taken from the Weather Data Summary for the Tri-State Winter Wheat study, Arkin et. al. (1979). Solar radiation was recorded at 3 sites within South Dakota for that study. Sites were located at Huron, Fort Pierre, and Lake Andes, SD. For the case of missing satellite data (this occured for 3 days in 1980) TIROS-N satellite images obtained by the Remote Sensing Institute were used to visually determine cloud cover across the state. Solar insolation values were then approximated accordingly. All solar radiation data are in langleys/day (1 langley = 1 cal/cm^2).

Air Temperatures

Air temperature data were obtained from Mr. William Lytle, state climatologist. Records for daily maximum and minimum temperatures from 120 reporting stations around South Dakota are summarized monthly in the "Climatological Data" bulletin published by the National Oceanic and Atmospheric Administration. Data from these summaries are recorded on computer tape and are kept on file at the National Climatic Center, Asheville, North Carolina. Both the tapes and summaries were acquired for this study.

Soil Properties

Soil moisture data sites were classified according to soil type utilizing the map of soil regions shown in Figure 6. This map is based on the soil classification system adopted by the National Cooperative Soil Survey of the Soil Conservation Service. In this system, soils are grouped according to soil temperature, soil moisture, parent materials, and general land use. Bulk densities for dominant soils in each region were obtained from the Soil Testing Laboratory at the SDSU Plant Science Department. The average bulk densities for the various regions are given in Table 4. These regional bulk densities were entered into the data base and used, along with the soil moisture data, to calculate volumetric moisture contents for all the sites.

TABLE 4

Bulk Densities for the Six Soil Type Regions Considered

Soil Type Classification ID	Average Bulk Densitiy (gm/cm³)
1	1.41
2	1.33
3	1.23
4	1.47
5	1.60
6	1.29

Soil Classification ID Key:

1. Deep soils formed mainly in glacial till or loamy glacial drift on uplands.
2. Deep soils formed in sandy to clayey lake sediments.
3. Deep soils formed mainly in loess, silty glacial drift, or loess mantled glacial till on uplands.
4. Soils formed mainly in residuum from clayey or silty shales on uplands.
5. Soil formed in mixed sandy and loamy materials, modified by wind and water, and residuum from sandstone, siltstone, and shale on uplands.
6. Soils formed in alluvium on bottom land.

DATA ANALYSIS

Data Processing

All data analysis was done on the IBM 370/148 computer at the SDSU computer center. The data base consisted of the soil moisture, air temperature, precipitation, and solar radiation data previously described. Soil moisture and precipation data were also entered into the Prime Computer at the Remote Sensing Institute. All data were accessed from magnetic tape or disk storage.

Programs were written to calculate soil moisture contents, precipitation totals, and potential and actual evapotranspiration rates. Calculations were done to determine the nearest precipitation, solar radiation, and air temperature reporting station to each soil moisture site location. The climatic data from these nearest stations were then assumed to be the climatic data at the actual soil moisture collection site.

Mapping work was done at the Remote Sensing Institute. Plots were made using the Hewlett-Packard 9825A computer and plotter at the Water Resources Institute and the IBM 6670 Information Distributor, laser printer at the computer center. Statistics were run using the Statistical Analysis System (SAS).

Because more data were available from small grain or pasture sites, this investigation was limited to deriving crop coefficients for small grain or pasture crops.

Potential Evapotranspiration Calculations

The Priestley-Taylor equation for calculating potential evapotranspiration rates is given by equation (19) as:

$$PET = (\alpha Rn)(Svp)$$

where,

PET = Potential evapotranspiration (mm/day)
α = proportionality constant for a particular crop and climate
s = Slope of the saturation vapor pressure curve at mean temperature (mb/°C)
γ = psychometric constant (.66 mb/°C)
Rn = net 24 hour radiation (mm/day)

Recall from equation (15) that:

$$\frac{s}{s+\gamma} = Svp$$

Several studies have been done to try to arrive at the best value of α for various crops. Priestley and Taylor (1972) analyzed measurements over numerous crop covers and climatic areas and concluded that the best overall mean for α was 1.26. Specifically they reported a mean α of 1.34 ± .05 for pasture and 1.30 ± .03 for a snap bean crop. Other results for α were summarized by Tanner and Jury (1976). They quoted values of α for grass ranging from 1.0 to 1.4. They also reported wheat to have an α value of 1.3. Similary, Kanemasu, et. al. (1976, 1977) suggested $\alpha = 1.35$ for wheat and corn, $\alpha = 1.28$ for sorghum, and $\alpha = 1.45$ for soybeans.

Since the values for grass or pasture varied considerably between studies, it was decided to use $\alpha = 1.28$. This value seemed reasonable because of the acute similarities in crop coefficients for pasture and sorghum as reported by Criddle (1958). The value of α = 1.33 was selected for small grains as a compromise between the reported values.

From kinetic theory of gases, it is apparant that the saturation vapor pressure increases with increasing temperature. It does not increase in a linear fashion, however. Thus, the slope of the saturation vapor pressure curve (s) also changes with temperature. Priestley and Taylor (1972) contended that the term **Svp** varied from .56 at 10°C to .82 at 35°C. Kanemasu (1979) proposed the following equation for the Svp term:

$$\boxed{Svp = .016\,T - 5 \times 10^{-6}\,T^{3} + 10^{-7}\,T^{4} + .4} \qquad (21)$$

Where, T is the average daily air temperature (°C). Using Kanemasu's equation, Svp was equal to .56 at 10°C and .89 at 35°C, in close accord with the Priestley and Taylor values. Therefore, the Kanemasu equation was used to calculate the Svp term.

Net and total daily solar radiation data were collected by another SDSU Physics Department project for numerous periods during the summer of 1981. Measurements were taken over an oats canopy. Regression analysis was run on the data and an equation relating total to net radiation was determined. Correlation coefficients in the range of r = 0.95 to r = 0.99 were obtained. This equation was used to calculate the net radiation for small grains from the solar radiation data. The net radiation equation for pasture was obtained from studies reported by Monteith (1976). These equations are given below.

1. small grain $\quad Rn = 0.797\ Rs - 172.4$ (langleys/day)
2. pasture $\quad Rn = 0.720\ Rs - 187.7$ (langleys/day)

(22)

To obtain the PET values in inches per day the net radiation had to be adjusted to inches per day using the following conversion:

$$Rn\ (cal/cm^2/day) \times \frac{1\ mm/day}{59\ cal/cm^2/day} \times \frac{1\ inch}{25.4\ mm} = Rn(inches/day) \tag{23}$$

Stephens (1965) grouped the Jensen-Haise equations into four major divisions dependent upon the average relative humidity of the region where the equation was to be applied. Figure 9 shows the humidity regions as defined by Stephens. The equation for the 40-50% division was selected for South Dakota and is given below.

$$PET = (.01067\ T - .2256)\ Rs/1500 \tag{24}$$

where,

PET = potential evapotranspiration (inches/day)
T = Average air temperature (°F)
Rs = Solar insolation (langleys/day)

Average daily air temperatures were calculated from the daily maximum and minimum values as:

$$T = (Tmax + Tmin)/2 \tag{25}$$

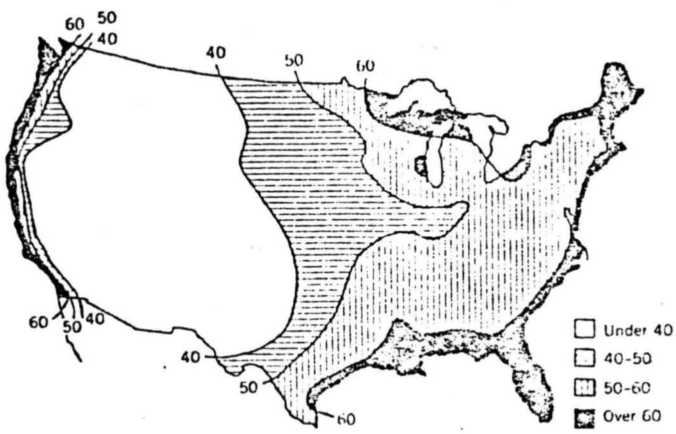


Figure 9: Jensen-Haise Humidity Regions

Water Balance Calculations

Using the water balance method (discussed earlier), the actual water lost through evapotranspiration was calculated. Runoff, drainage, and subsurface lateral movement were all considered negligible. The soil moisture profile was considered to a depth of three feet. The water balance equation used is given below.

$$SM(f) = SM(i) - AET + P \tag{26}$$

where,

SM(f) = final soil moisture content (inches)
SM(i) = initial soil moisture content (inches)
P = total precipitation occurring between initial and final soil moisture measurements (inches)
AET = total actual evapotranspiration occurring between initial and final soil moisture measurements (inches)

Rearranging,

$$AET = SM(i) - SM(f) + P \tag{27}$$

Actual evapotranspiration was calculated in this manner from the soil moisture and precipitation data.

Crop Coefficient Calculations

Actual evapotranspiration should be related to potential evapotranspiration by a crop coefficient. This crop factor should vary throughout the growing season by the development stages of the plant. By convention, these crop coefficients (also called k- values) were represented by the symbol k and calculated in the following manner:

$$AET = kPET \tag{28}$$

therefore,

$$kPET = SM(i) - SM(f) + P \tag{29}$$

or,

$$k = (SM(i) - SM(f) + P)/PET \tag{30}$$

Where the k- value is for the period between the initial and final moisture measurements.

If the crop coefficient is to be of value in adjusting potential evapotranspiration equations to particular regions, it must be year invariant. Otherwise, the k- values would need to be recalculated for each growing season after the season had concluded. This would be useless for soil moisture prediction applications. Therefore, the 1979 and 1980 data were used jointly to compute k- values for crop regions within South Dakota. The 1981 data could then be used to test the predictability of these coefficients. Complete description of the results follows in the Results section.

RESULTS

Hypothesis

Other researchers have suggested that the crop coefficient varies with the development stages of the plant. Therefore, a parameter which is representative of crop growth could presumably determine the crop coefficient. Either leaf area index (LAI) or percent cover which reflect the growing cycle of the plant could be this parameter.

Leaf area index is defined by Monteith (1975) as "the area of leaves (upper side only) within a vertical cylinder of unit cross section and equal in height to the height of the foliage". It is a dimensionless quantity which is expressed as leaf area per ground area. Percent cover as measured in this study is the percentage of vegetation covering the ground surface as viewed vertically downward approximately 1.5 meters above the ground surface. Figure 10 (from Monteith, 1976) and Figure 11 (from Heilman and Moore) depict the changes in leaf area index for pasture and small grain crops during the growing season. Percent cover approximately follows the leaf area index curve, until the end of the season when leaf area indices decline yet percent cover values remain relatively high. As shown in Figure 11, the leaf area index curve for small grains has a definite peak. On the other hand, the LAI curve for pasture (shown in Figure 10) is rather flat. This is not surprising since pasture is a perennial and would not have a large leaf area index change during the growing season. However, small grains, which must be planted, would be expected to have an ever increasing leaf area index as more and more leaves develop. At both the beginning and end of the growing cycle the leaf area index for small grains is near zero.

Similarly, the transpiration component of small grain evapotranspiration would be expected to increase with the amount of leaf area present to transpire. At the same time the evaporation component would be decreasing due to less exposed bare soil. Since transpiration is the larger contributor to evapotranspiration (Sellers 1969), the overall effect would be an increasing actual evapotranspiration rate. Recall that the potential evapotranspiration rate was defined for a surface with complete canopy cover. As the canopy develops fully the actual evapotranspiration rate should approach the potential rate (assuming soil moisture is not limiting). Likewise, the crop coefficient should approach its maximum value. Presumably k (max) = 1 at that point since the potential rate is the maximum rate that should occur. Conversely, low values of k would be expected for an incomplete canopy. The k-values would then increase as the canopy developed. Thus, it appears likely that the crop coefficients could be a function of leaf area index.

Moreover, the crop coefficients for pasture and grain should differ. Transpiration is the major component of evapotranspiration for a pasture since little or no bare soil is present. In addition, the transpiration component varies only slightly due to canopy development

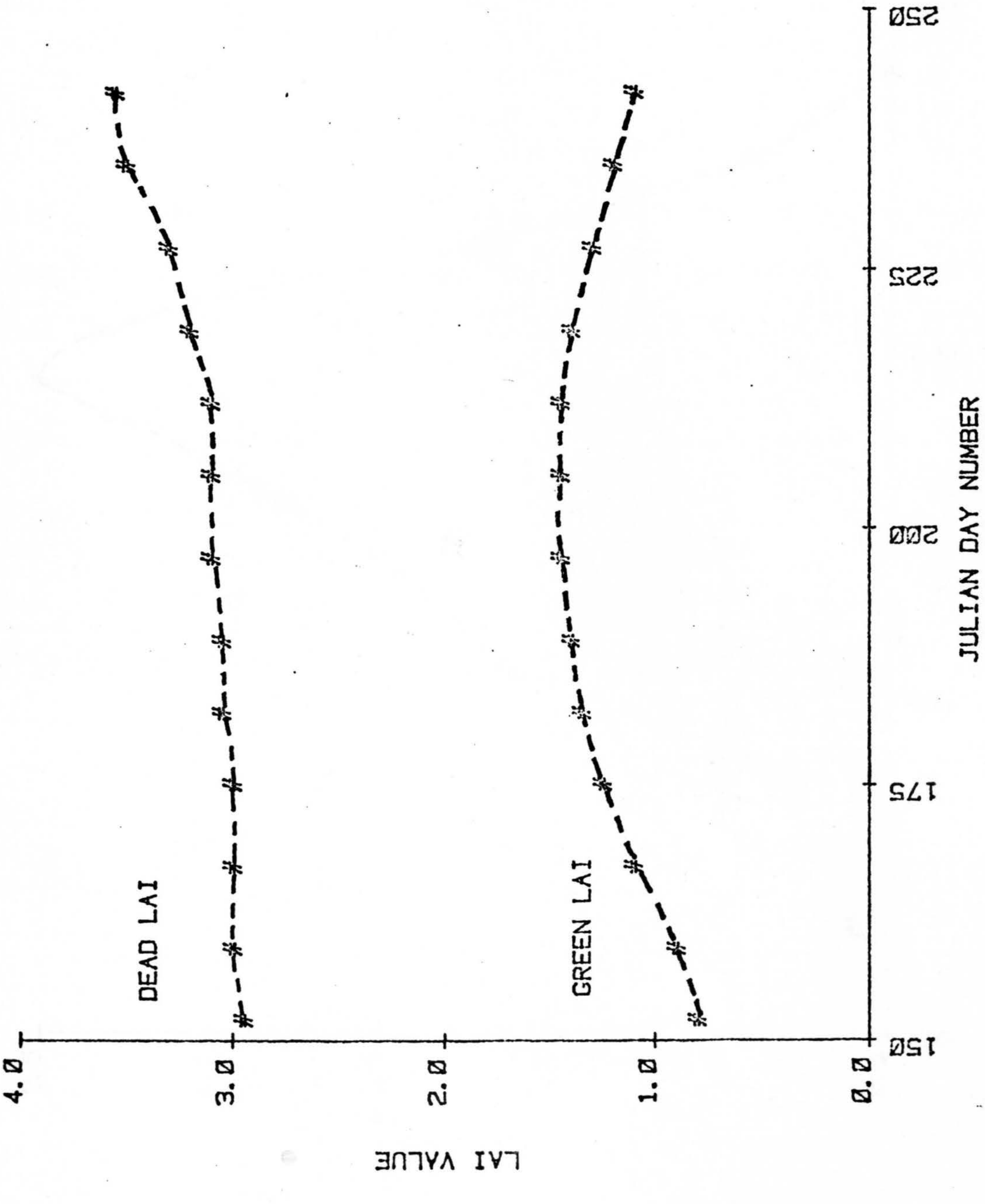


Figure 10: Leaf Area Index Curve for Pasture.

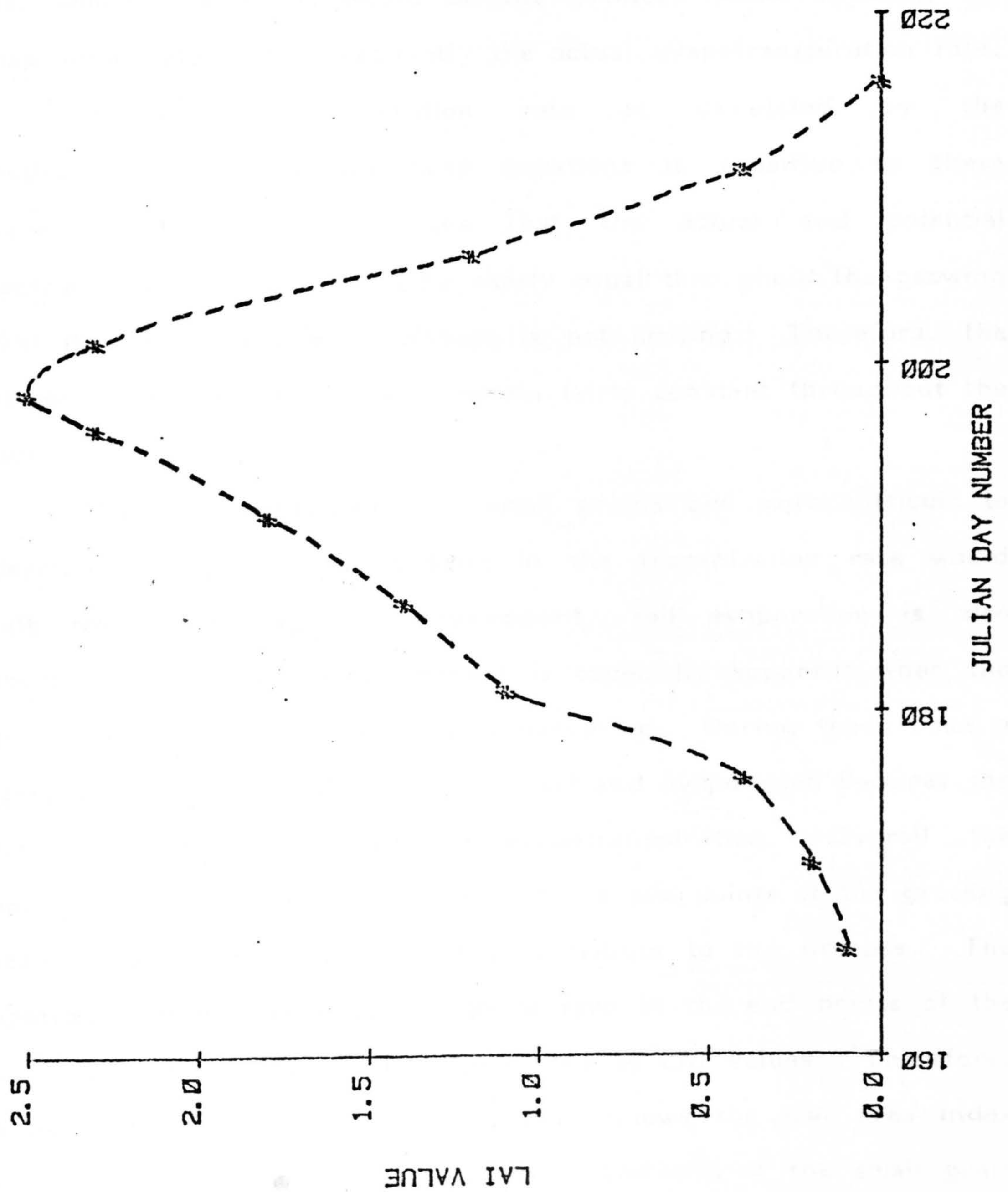


Figure 11: Leaf Area Index Curve for Small Grain.

during the season since a complete crop canopy is already established. Thus, climatic variations would be the greatest factor affecting the transpiration rate and consequently the actual evapotranspiration rate. The potential evapotranspiration rate as calculated by the Priestley-Taylor and Jensen-Haise equations is sensitive to these climatic variations. This means that the actual and potential evapotranspiration rates should be nearly equal throughout the growing period if one assumes soil moisture is not limiting. Therefore, the k-values for pasture should also remain fairly constant throughout the season.

The crop coefficients for small grains are more difficult to understand. Although an increase in the transpiration rate would result from increasing leaf development, soil evaporation is also present. The evaporation component is especially apparent when the grain is newly planted or after it is harvested. During those times a large portion of the land area is bare soil and evaporation becomes the major (or only) component of evapotranspiration. Overall the evapotranspiration rate would be less at the end points of the growing season since transpiration does not contribute to the process. The evapotranspiration rate does not go to zero at the end points of the growing period and could not be predicted by LAI values. Therefore, the assumption that the crop coefficient follows the leaf area index curve can not be valid at the beginning and end of the small grain season.

Thus when soil moisture is not limiting, the following hypotheses about the crop coefficients were made:

1. Coefficients for pasture should be quite constant throughout the growing season and could be represented by a function of LAI or percent cover.
2. Coefficients for small grain could be represented by a function of LAI or percent cover except near the end points of the growing season when evaporation becomes the major component of evapotranspiration.

Analysis

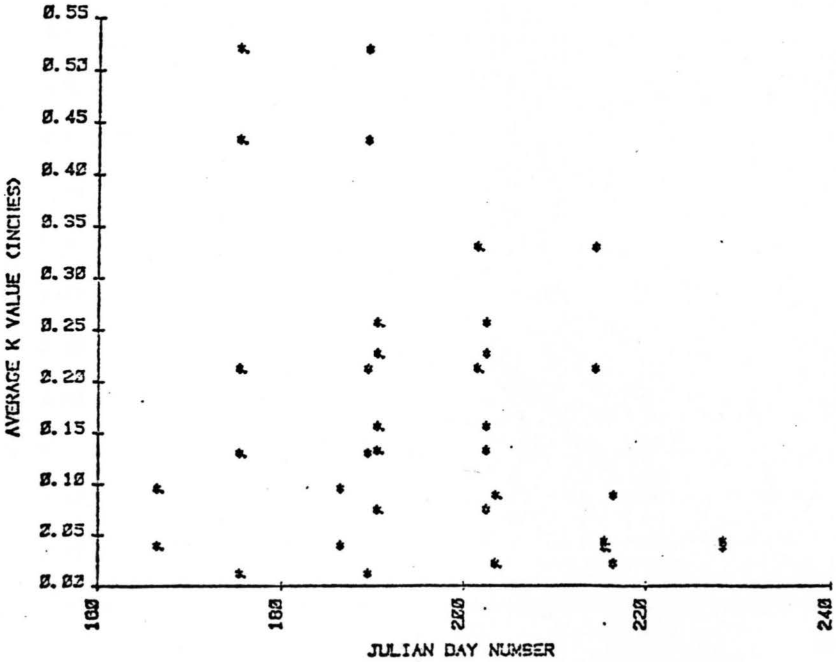
To analyze the crop coefficients, plots were made of the coefficients versus Julian date for each soil moisture site. The soil moisture sites were identified by site number, type of crop canopy, cropping region (see Figure 7), soil type region (see Figure 6), and year sampled. Plots for individual sites were grouped according to each of the above categories. All plots within the same category were compared for similarities or trends within that category. For example, sites located in the same crop region were examined for a trend among the k-values in that region. All the crop regions were then compared to determine if the coefficients did show different trends for different regions. This process was repeated for each category (crop type, cropping region, soil type region, and year sampled). Since each soil moisture site was sampled only five times during 1979 and 1980, trends were difficult to detect, particularly for crop coefficient curve shape.

However, some tentative conclusions could be made from the plotting results.

No trends within cropping region or soil type region could be found. Also, no differences in coefficients between crop regions or soil regions were detectable. Figure 12 shows a comparison between two crop regions. Notice the scatter of points within each region confirming that a trend within the region was not discernable. Also notable is the fact that both regions appear equally scattered, further evidence that variation in crop coefficients between regions was not apparant. Similar plots for two soil regions are shown in Figure 13.

Assuming that the curve throughout the growing season for the crop coefficients resembles a leaf area index curve, the pasture and small grain plots should vary differently with time. Some of the pasture and small grain sites did have coefficient plots which paralleled their respective leaf area index curves. Examples for both crops are given in Figure 14 and Figure 15. However, most sites did not have enough data points to detect any functional relationship of the coefficients. In addition, a plot of all the grain sites or the pasture sites revealed no particular functional dependency of the k-values.

One distinct and important difference was detected from this plotting exercise. The k-values were not year invariant. In fact, k-values for the same site or neighboring sites often varied greatly between 1979 and 1980. Figure 16 and Figure 17 depict the contrast in crop coefficients for neighboring sites between the two years. Notice that the plots for each year are very different. Also the shift in



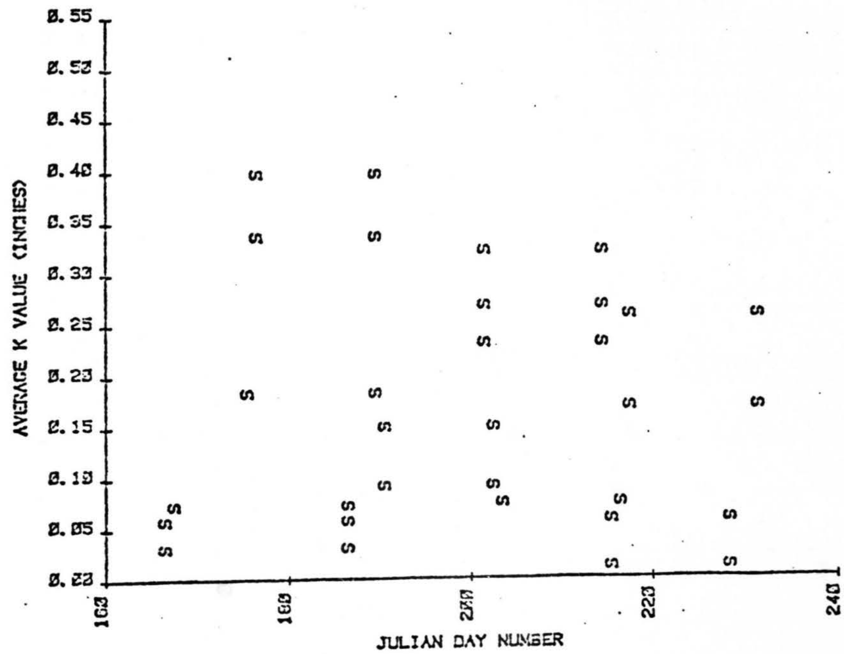


Figure 12: Crop Coefficients for 2 Cropping Regions.

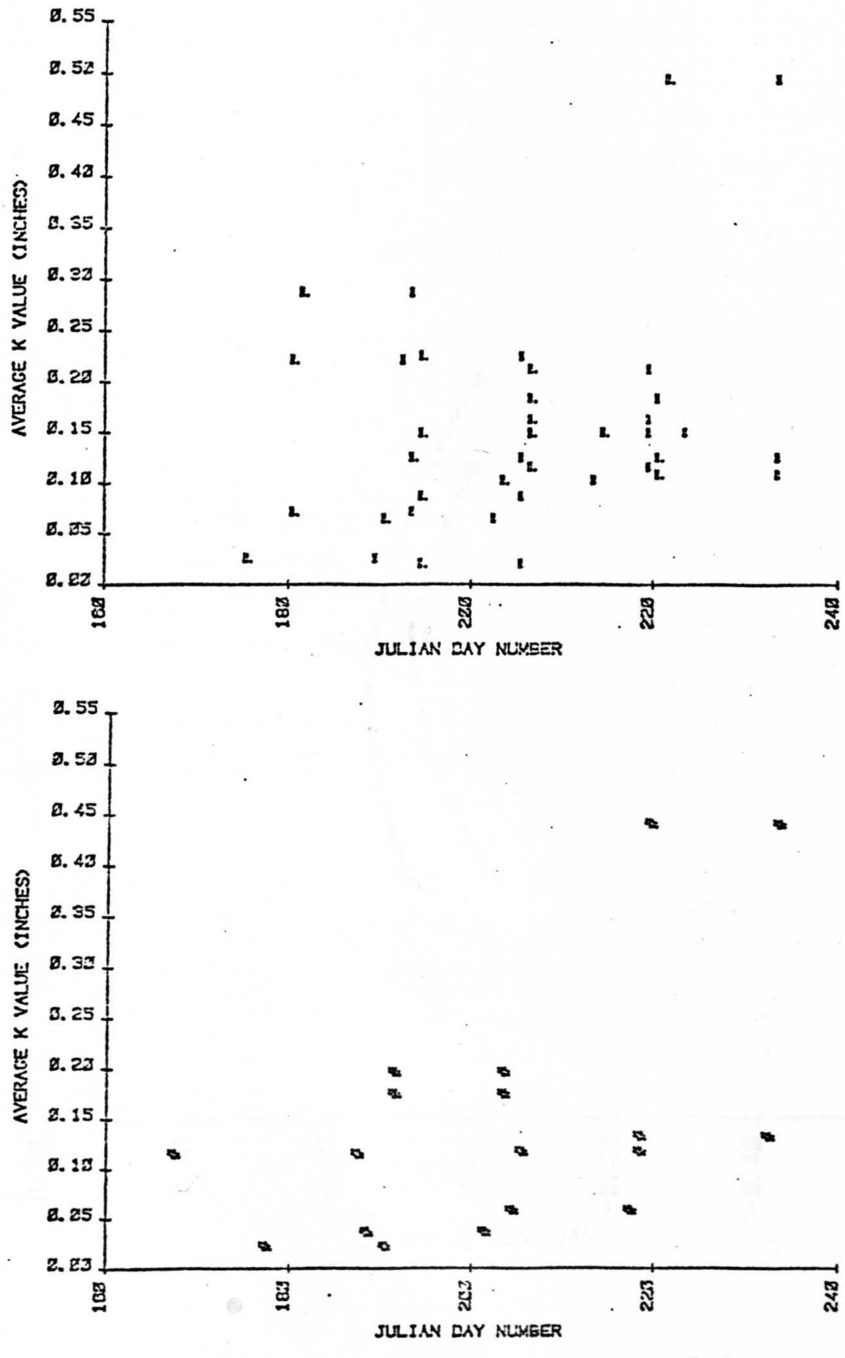


Figure 13: Crop Coefficients for 2 Soil Regions.

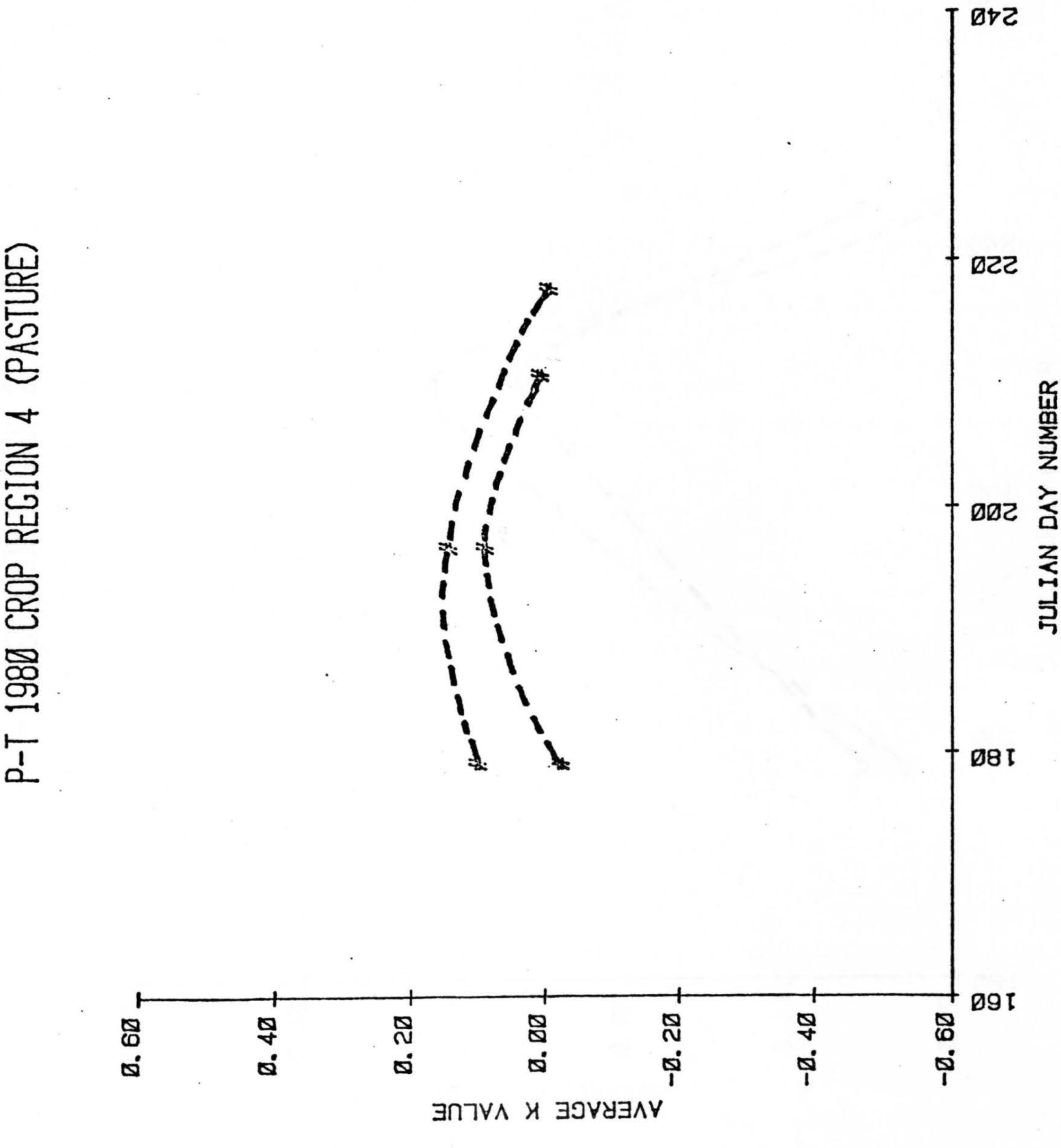


Figure 14: Crop Coefficient Curve for 2 Pasture Sites.

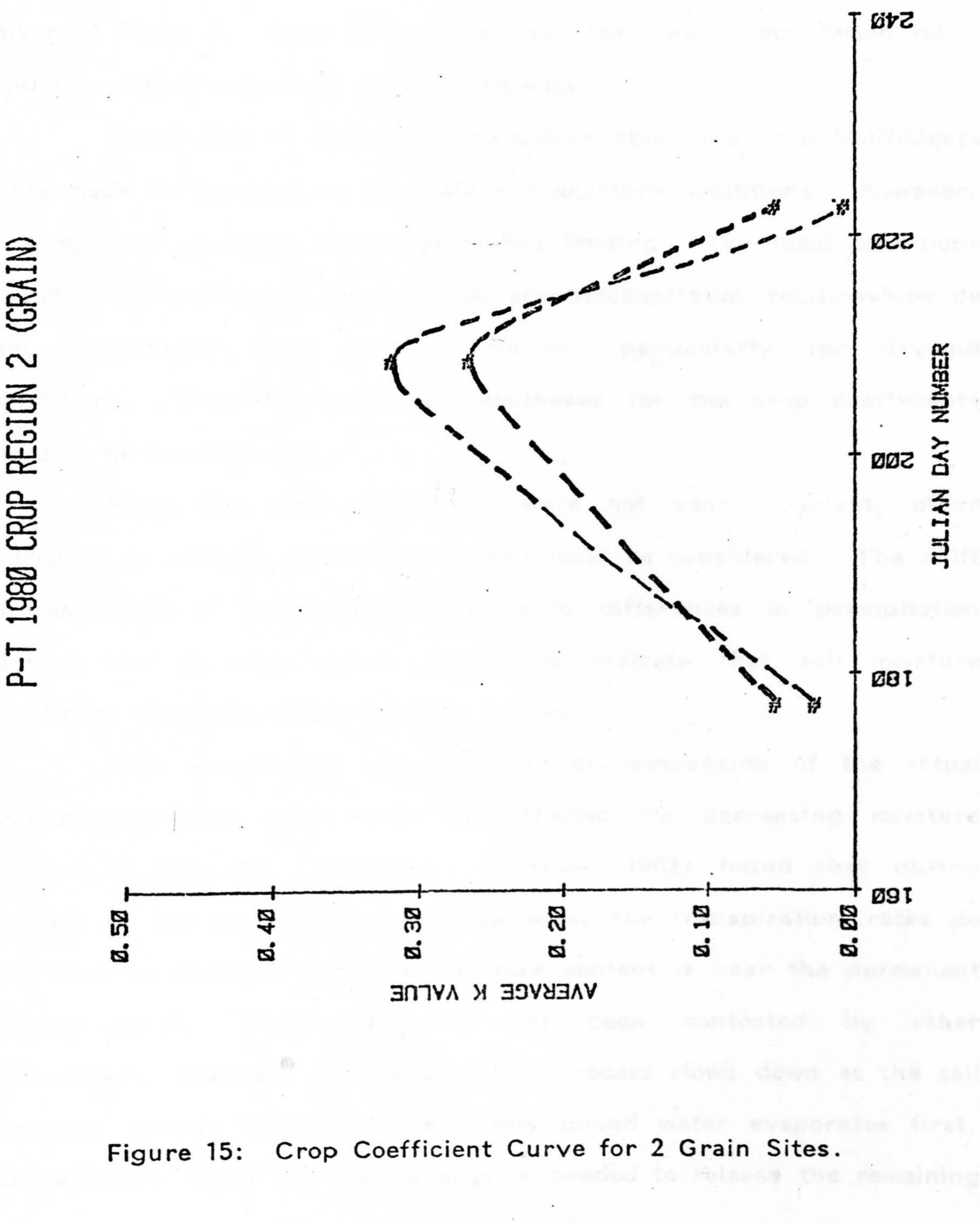


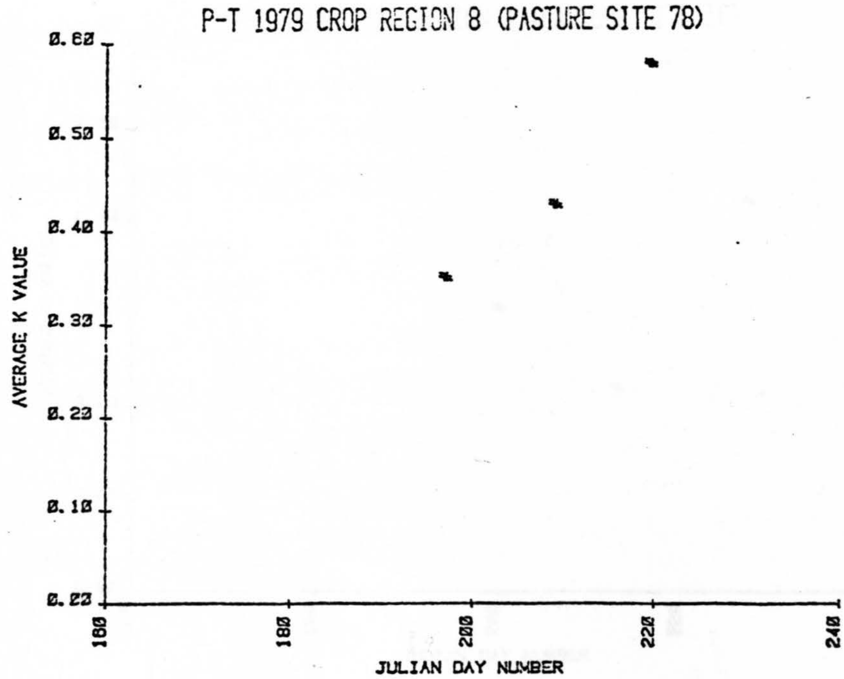
Figure 15: Crop Coefficient Curve for 2 Grain Sites.

magnitude of the coefficients between the two years is very apparant. Precipitation totals for these sites according to Julian date and year are given in Table 5. Sites 94 and 108 have the lower precipitation totals and the smaller magnitude crop coefficients.

Recall that all previous assumptions about the crop coefficients were made by considering adequate soil moisture conditions. However, soil moisture is often, if not generally, limiting. The ideal conditions assumed when deriving the potential evapotranspiration relationships do not consistently hold true in nature, particularly for dryland conditions. Thus the previous hypotheses for the crop coefficients need to be revised.

Since the crop coefficients were not year invariant, other variables in addition to leaf area index must be considered. The shift in magnitude of the coefficients due to differences in precipitation during the growing season seemed to indicate that soil moisture conditions were also affecting the k-values.

Both evaporation and transpiration components of the actual evapotranspiration rate would be affected by decreasing moisture content in the soil. Denmead and Shaw (1962) found that during periods of low potential evapotranspiration the transpiration rates do not start to decrease until the moisture content is near the permanent wilting point. This conclusion has been contested by other researchers, however. The evaporation process slows down as the soil moisture becomes limiting. The loosely bound water evaporates first. Consequently, more and more energy is needed to release the remaining



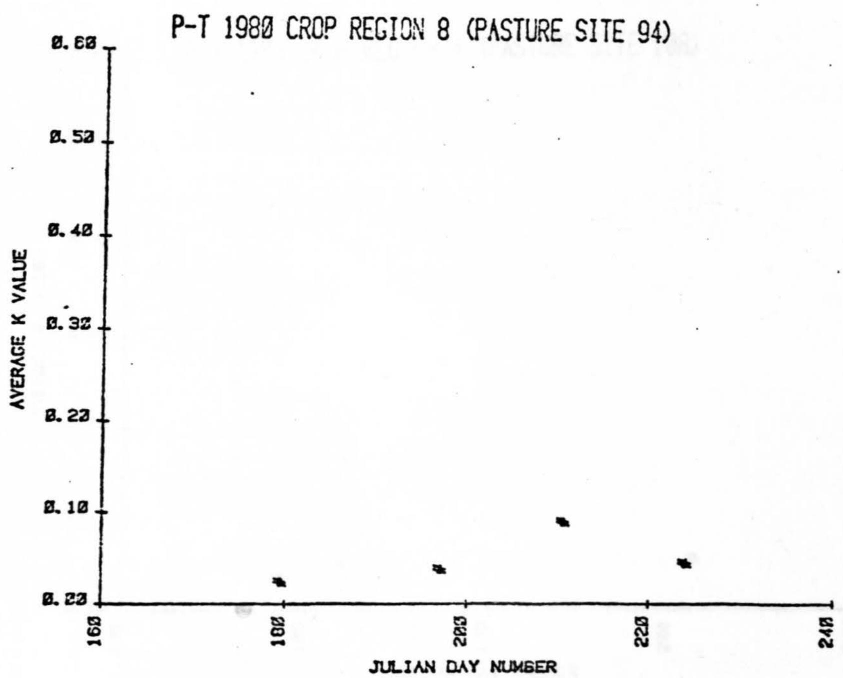


Figure 16: Differences in k-values Between 1979 and 1980.

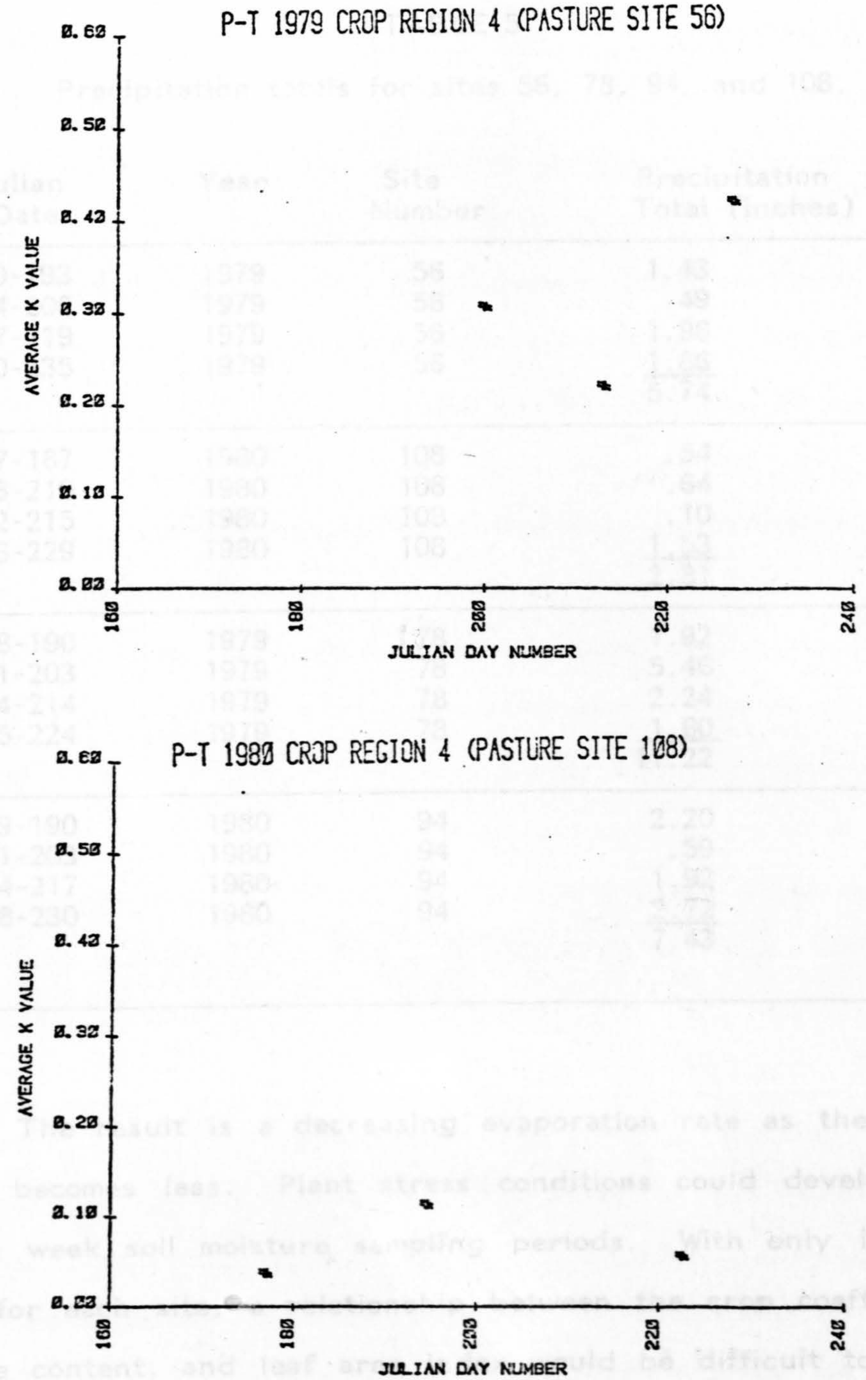


Figure 17: Differences in k-values Between 1979 and 1980.

TABLE 5

Precipitation totals for sites 56, 78, 94, and 108.

Julian Date	Year	Site Number	Precipitation Total (inches)
180-193	1979	56	1.43
194-206	1979	56	.49
207-219	1979	56	1.96
220-235	1979	56	1.86
			5.74
167-187	1980	108	.54
188-210	1980	108	.64
202-215	1980	108	.10
216-229	1980	108	1.53
			2.81
176-190	1979	78	1.92
191-203	1979	78	5.46
204-214	1979	78	2.24
215-224	1979	78	1.60
			11.22
169-190	1980	94	2.20
191-203	1980	94	.59
204-217	1980	94	1.92
218-230	1980	94	2.72
			7.43

water. The result is a decreasing evaporation rate as the soil water content becomes less. Plant stress conditions could develop between the two week soil moisture sampling periods. With only limited data points for each site, a relationship between the crop coefficient, soil moisture content, and leaf area index would be difficult to detect by merely graphing the data.

Therefore, statistics were used to determine if a soil moisture - plant relationship did exist with the crop coefficients and whether that relationship was significant. The soil moisture - plant variables considered were: profile soil moisture percent surface soil moisture, logarithm (base e) of the profile moisture percent cover (no LAI values were measured), and the interactions among these variables. The data set was partitioned by crop and by year. Statitics were run on the following partitions: 1979 grain sites, 1979 pasture sites, 1979 sites (pasture and grain), 1980 grain sites, 1980 pasture sites, 1980 sites (pasture and grain), all sites (pasture and grain 1979-80), grain sites (1979-80), and pasture sites (1979-80).

Correlation and stepwise multiple linear regression results were computed for each of the data partitions. The SAS correlation technique used in this analysis calculates the correlation coefficient between each variable in the input data set with every other variable in the set. Levels of significance for each correlation coefficient are also given. The multiple linear regression analysis was done using the SAS Stepwise Maximum R^2 improvement method (MAXR). This technique is generally considered superior to either the Forward Selection or Backward Selection procedures. The MAXR method begins by determining which independent variable produces the highest R^2 value with the dependent variable (R^2 is often called the coefficient of multiple determination). This result is the "best" one-variable model. For each additional independent variable added into the model, the MAXR method determines whether removing one variable and replacing it with another variable would increase the R^2 even more. This way the MAXR technique finds the "best" model that can be achieved. All possible arrangements of independent variables are compared before the final model is formed. An example of a model is:

$$Y = B0 + B1X1 + B2X2 \tag{31}$$

where Y is the dependent variable, X1 and X2 are independent variables, B0 is the intercept, and B1 and B2 are coefficients calculated by MAXR. Any number of variable models can be produced (up to the total number of independent variables defined). F-tests are made on each model produced. The F-values and the significance levels are included in the output.

Correlation

No significant correlation was found to exist between the k-values and the log (base e) of the profile soil moisture content for any of the data partitions. Therefore, this independent variable was excluded from further study. In addition, k-values predicted by either the Jensen-Haise or Priestley-Taylor equation did not vary appreciably.

Each of the pasture site partitions failed to show significant correlation between the crop coefficients and any of the independent variables (surface moisture, percent cover, profile moisture, and all interactions). Surface moisture and cover did have a significant (.05 level or better) correlation for the 1979 pasture, 1980 pasture, and all pasture (1979-80) partitions. These results are given in Table 6.

Both the 1979 grain and all grain (1979-80) data sets had a significant negative correlation between the crop coefficient and surface soil moisture. Significant positive correlations between the k-values and profile moisture, cover, and profile/cover interaction were also noted for both data sets. However, the 1980 grain sites showed no significant correlations. Table 7 lists the correlation results for the grain sites.

For the 1979 grain data set, the k-value had a correlation coefficient of $r = -0.37881$ with surface moisture (see Table 7). This gives an r^2 of 0.1435 or 14.35%. Therefore, 14.35% of the variation in the values of k may be accounted for by the linear relationship with the surface moisture variable. The sign of the correlation coefficient (r) implies a linear relationship with a negative slope between these two variables.

Interpreting the magnitude of the r value is more difficult. One can conclude that there is essentially no linear relationship between the dependent variable and the independent variable when $r = 0$. The result would be a horizontal regression line and any knowledge of the independent variable would be useless in predicting the dependent variable. It is incorrect to conclude that an $r = 0.8$ implies a relationship twice as linear as an $r = 0.4$. Therefore, the null

TABLE 6

Correlation Coefficients for Pasture.

RESULTS FROM 1979 DATA (PASTURE)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 119

	SURFACE	COVER	K	PROFILE	IPRCOV	ISFCOV
SURFACE	1.00000 0.0000	0.19195 0.0365	0.04830 0.6019	0.10638 0.2496	0.18805 0.0406	0.97523 0.0001
COVER	0.19195 0.0365	1.00000 0.0000	0.00521 0.9551	-0.10664 0.2484	0.29766 0.0010	0.36934 0.0001
K	0.04830 0.6019	0.00521 0.9551	1.00000 0.0000	0.04020 0.6642	0.03318 0.7202	0.05881 0.5252
PROFILE	0.10638 0.2496	-0.10664 0.2484	0.04020 0.6642	1.00000 0.0000	0.90943 0.0001	0.09179 0.3208
IPRCOV	0.18805 0.0406	0.29766 0.0010	0.03318 0.7202	0.90943 0.0001	1.00000 0.0000	0.24331 0.0077
ISFCOV	0.97523 0.0001	0.36934 0.0001	0.05881 0.5252	0.09179 0.3208	0.24331 0.0077	1.00000 0.0000

RESULTS FROM 1980 DATA (PASTURE)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 116

	SURFACE	COVER	K	PROFILE	IPRCOV	ISFCOV
SURFACE	1.00000 0.0000	0.25211 0.0063	-0.05850 0.5328	-0.00906 0.9231	0.06309 0.5011	0.98909 0.0001
COVER	0.25211 0.0063	1.00000 0.0000	0.02838 0.7623	0.08785 0.3484	0.41226 0.0001	0.33968 0.0002
K	-0.05850 0.5328	0.02838 0.7623	1.00000 0.0000	0.06193 0.5090	0.06516 0.4871	-0.05457 0.5607
PROFILE	-0.00906 0.9231	0.08785 0.3484	0.06193 0.5090	1.00000 0.0000	0.93712 0.0001	-0.00853 0.9276
IPRCOV	0.06309 0.5011	0.41226 0.0001	0.06516 0.4871	0.93712 0.0001	1.00000 0.0000	0.09420 0.3145
ISFCOV	0.98909 0.0001	0.33968 0.0002	-0.05457 0.5607	-0.00853 0.9276	0.09420 0.3145	1.00000 0.0000

TABLE 7

Correlation Coefficients for Small Grain.

RESULTS FROM 1979 DATA (GRAIN)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 61

	SURFACE	COVER	K	PROFILE	IPRCOV	ISFCOV
SURFACE	1.00000 0.0000	-0.20118 0.1200	-0.37881 0.0026	-0.16955 0.1914	-0.19744 0.1272	0.88583 0.0001
COVER	-0.20118 0.1200	1.00000 0.0000	0.26227 0.0412	0.10800 0.4074	0.42946 0.0006	0.24709 0.0549
K	-0.37881 0.0026	0.26227 0.0412	1.00000 0.0000	0.28636 0.0253	0.31993 0.0120	-0.27491 0.0320
PROFILE	-0.16955 0.1914	0.10800 0.4074	0.28636 0.0253	1.00000 0.0000	0.91730 0.0001	-0.10063 0.4403
IPRCOV	-0.19744 0.1272	0.42946 0.0006	0.31993 0.0120	0.91730 0.0001	1.00000 0.0000	0.00921 0.9438
ISFCOV	0.88583 0.0001	0.24709 0.0549	-0.27491 0.0320	-0.10063 0.4403	0.00921 0.9438	1.00000 0.0000

RESULTS FROM COMPLETE GRAIN DATA SET (1979-1980)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 92

	SURFACE	COVER	K	PROFILE	IPRCOV	ISFCOV	IPRSF
SURFACE	1.00000 0.0000	-0.03665 0.7287	-0.25398 0.0146	-0.10552 0.3168	-0.10039 0.3410	0.93160 0.0001	0.70768 0.0001
COVER	-0.03665 0.7287	1.00000 0.0000	0.20245 0.0529	0.14578 0.1656	0.47098 0.0001	0.27498 0.0080	0.06308 0.5502
K	-0.25398 0.0146	0.20245 0.0529	1.00000 0.0000	0.20856 0.0460	0.22464 0.0313	-0.19221 0.0664	0.00084 0.9936
PROFILE	-0.10552 0.3168	0.14578 0.1656	0.20856 0.0460	1.00000 0.0000	0.92109 0.0001	-0.05473 0.6044	0.55110 0.0001
IPRCOV	-0.10039 0.3410	0.47098 0.0001	0.22464 0.0313	0.92109 0.0001	1.00000 0.0000	0.05130 0.6272	0.48882 0.0001
ISFCOV	0.93160 0.0001	0.27498 0.0080	-0.19221 0.0664	-0.05473 0.6044	0.05130 0.6272	1.00000 0.0000	0.69642 0.0001
IPRSF	0.70768 0.0001	0.06308 0.5502	0.00084 0.9936	0.55110 0.0001	0.48882 0.0001	0.69642 0.0001	1.00000 0.0000

hypothesis that the slope = 0 (no linear relationship) versus the alternate hypothesis that the slope ≠ 0 is tested instead. The significance level to which the null hypothesis can be rejected is given below each correlation coefficient. For 1979 grain, the correlation coefficient between k and surface ($r = -0.37881$) has a level of significance of 0.0026. This means that the null hypothesis may be rejected at the 0.0026 level of significance. In other words, the probability of rejecting the null hypothesis when it is actually true (Type I error) is 0.0026. If the probability of committing a Type I error is 0.05 or less one can be almost positive that the null hypothesis should be rejected (this is often termed a "significant" result). Returning to the 1979 grain results, the hypothesis that no linear relationship between crop coefficient and surface moisture can therefore be rejected with 0.0026 probability for error.

The significant correlations noted in the entire grain data set (1979-80) could be due to the fact that there were many more grain sites during the 1979 sampling period. Thus, the entire data set was probably influenced mainly by the 1979 sites and would reflect similar results.

No significant correlation was found for any of the pasture site k-values, yet significant correlation was found for some of the grain site coefficients. Therefore, a variable which is present only for grain sites must be affecting the k-values. Exposed bare soil would be such a variable. Table 7 shows that the k-values had a significant correlation with surface moisture (negative), profile moisture, and profile/cover interaction. This would mean that higher surface moisture contents resulted in generally lower k-values. On the other hand, larger profile moisture contents and larger profile/cover values corresponded to higher k-values. Presumably surface moisture would be depleted by the evaporation process and profile moisture by the transpiration process. More leaf area should also lead to higher transpirative demand. For pasture, the major component of actual evapotranspiration is transpiration. However, the actual evapotranspiration rate for grain sites is influenced by both evaporation and transpiration. Apparantly the k-values are strongly affected by the evaporation process and the presence of bare soil. The crop coefficients correlate with soil moisture only when the evaporation process is a major contributor to the actual evapotranspiraiton rate (the small grain situation).

High surface moisture leads to an increase in the evaporation rate and an apparant decrease in the k-values. During periods when the transpiration rate should be increasing while the evaporation rate is decreasing (leaf area development), the coefficients show a tendency to increase. These results could be interpreted to indicate that changes in the evaporation rate are controlling changes in the k-values. From the statistical results, the k-values seem to vary inversely with changes in the evaporation rate. This conclusion would explain the lack of significant correlation on the pasture sites. Evaporation is such a small component of actual evapotranspiration for pasture that changes in the evaporation rate would affect the actual evapotranspiration rate very little. Even though changes in the evaporation rate may lead to changes in the crop coefficients, correlation between these two variables would not be detectable on pasture sites. The pasture sites did show a significant positive correlation between surface moisture and percent cover. Apparently the increasing surface moisture causes more plant growth to occur. This effect would tend to obscure the evaporation component of evapotranspiration even more.

MAXR

The MAXR technique was used to study further the affects of the independent variables on the k-values. MAXR calculates the coefficient of multiple determination (R square) as well as the appropriate F-values. The R square value indicates what proportion of the total variation in the dependent variable is explained by the fitted linear model. Table 8 gives an example of the MAXR output for the complete 1979 data set. The R square value for the best two variable model is 0.03140404. This result can be interpreted to mean that 3.14% of the variation in the k-values is explained by the linear model with surface and surface/cover interaction as the independent variables. The regression explained by the model is significant to the 0.0594 level. The surface variable (in the presence of the surface/cover interaction) is significant to the 0.0183 level and the surface/cover interaction (in the presence of the surface) is significant to the 0.0305 level. All MAXR results with significance levels of .05 or less are given in Appendix A.

TABLE 8

MAXR Results for 1979 (Pasture and Grain) Data Set.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE IPRCOV ENTERED R SQUARE = 0.01800809 C(P) = 4.18414560

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.36363276	0.36363276	3.26	0.0725
ERROR	178	19.82910686	0.11139948		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.02912278				
IPRCOV	0.00018818	0.00010415	0.36363276	3.26	0.0725

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE SURFACE ENTERED R SQUARE = 0.02513904 C(P) = 4.87569952

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.50762610	0.25381305	2.28	0.1051
ERROR	177	19.68511352	0.11121533		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.07034732				
SURFACE	-0.00265505	0.00233337	0.14399334	1.29	0.2567
IPRCOV	0.00019783	0.00010441	0.39923776	3.59	0.0598

STEP 2 IPRCOV REPLACED BY ISFCOV R SQUARE = 0.03140404 C(P) = 3.72614389

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.63413368	0.31706684	2.87	0.0594
ERROR	177	19.55860593	0.11050060		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.16680017				
SURFACE	-0.01783339	0.00749092	0.62627043	5.67	0.0183
ISFCOV	0.00017678	0.00008105	0.52574535	4.76	0.0305

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

As before, the pasture sites showed no significant linear regression between the k-values and any of the independent variables. Generally, the grain sites showed significant regression results when including the variables of soil moisture (profile and surface) and soil moisture/cover interaction in the fitted model. Surface moisture and surface moisture/cover interaction added negatively into the models. At most only 20% of the total variation in the k-values was explained by any of the calculated models. The MAXR results strengthened the hypothesis that changes in the evaporation rate are the major factor affecting the k-values. Plots of the raw data points and the MAXR fitted models follow in Figures 18-30. The data points are too scattered to notice any correlation between the fitted data lines and the data itself. The plots are included to show visually the results of the statistical analysis. See Appendix A for the individual MAXR results and Appendix B for a listing of the raw data. Due to the small number of grain sites sampled during 1981, the crop coefficient models could not be adequately tested.

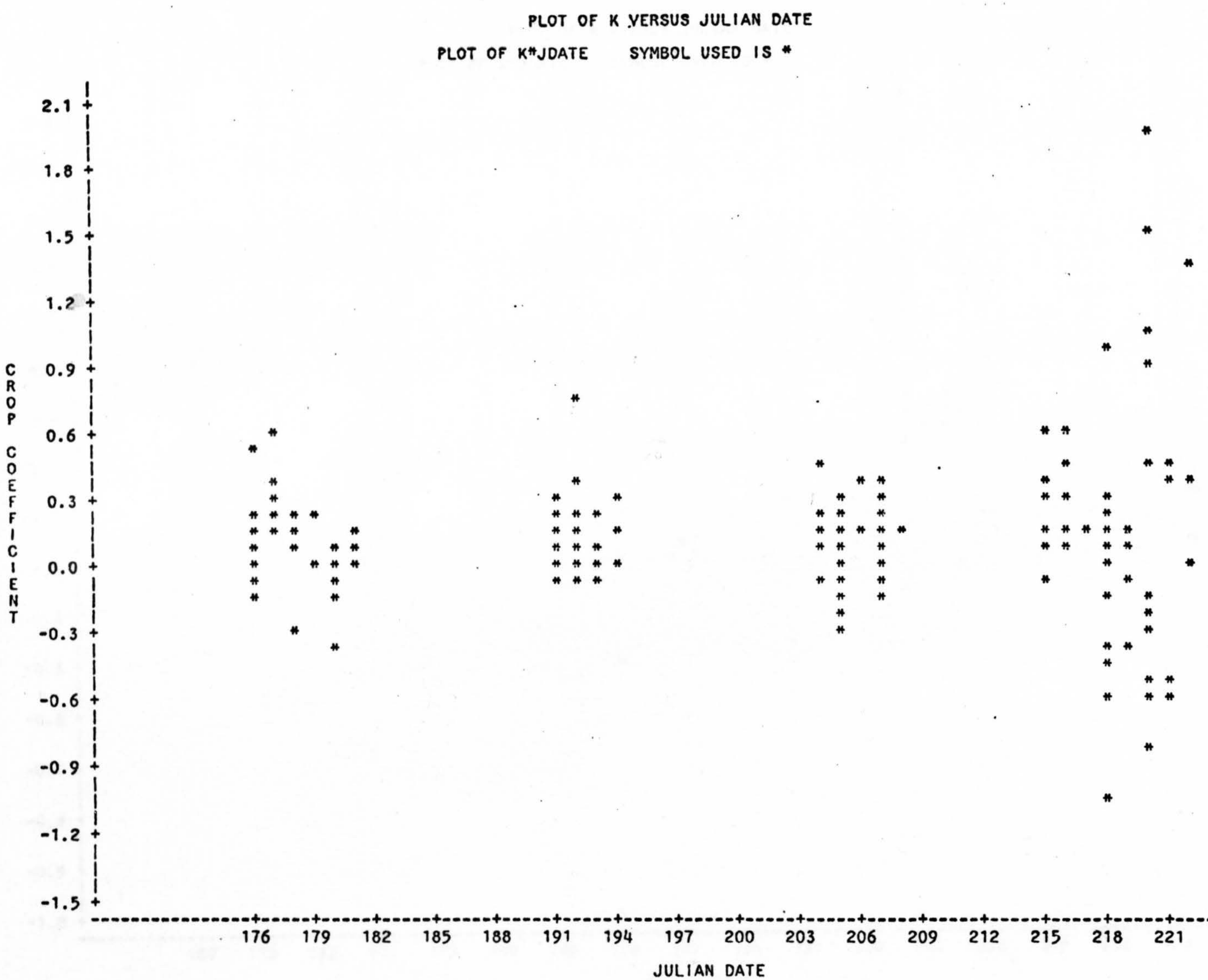


Figure 18: Plot of 1979 Data.

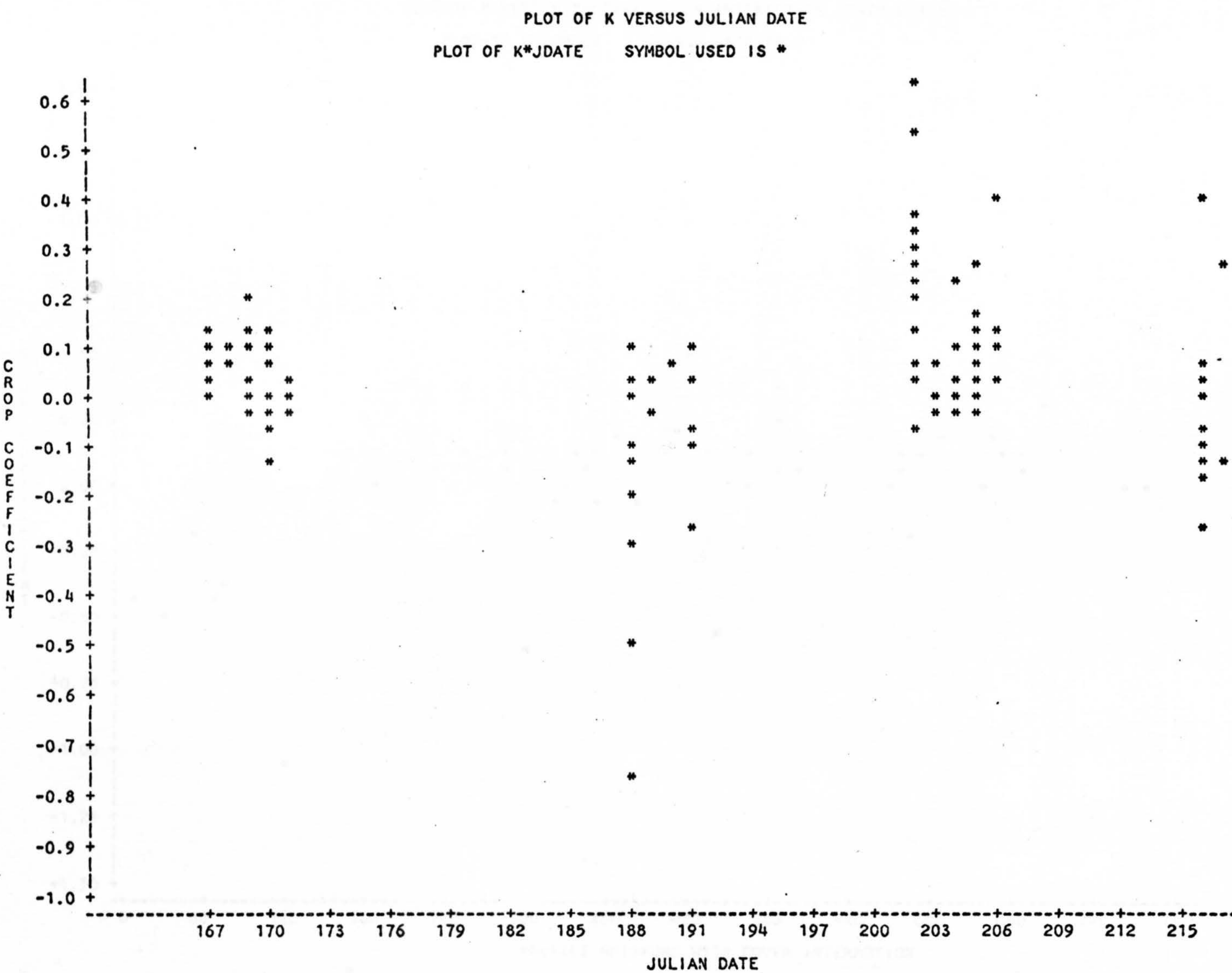


Figure 19: Plot of 1980 Data.

PLOT OF K VERSUS PROFILE COVER INTERACTION (1979 GRAIN)

PLOT OF K*IPRCOV   SYMBOL USED IS *

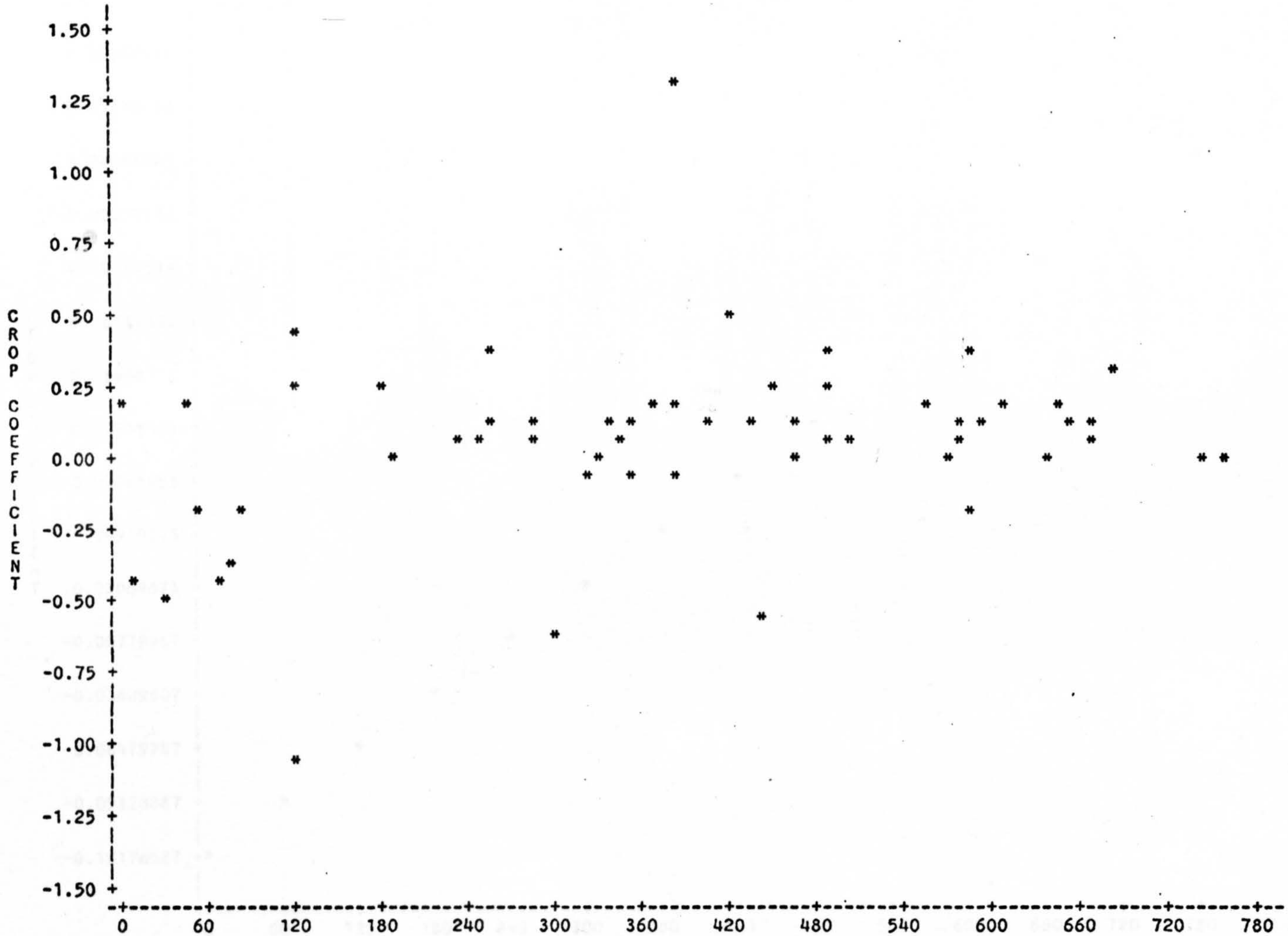


Figure 20

PLOT OF K AS A FUNCTION OF INTERACTION (1979 GRAIN)

PLOT OF K*IPRCOV   SYMBOL USED IS *

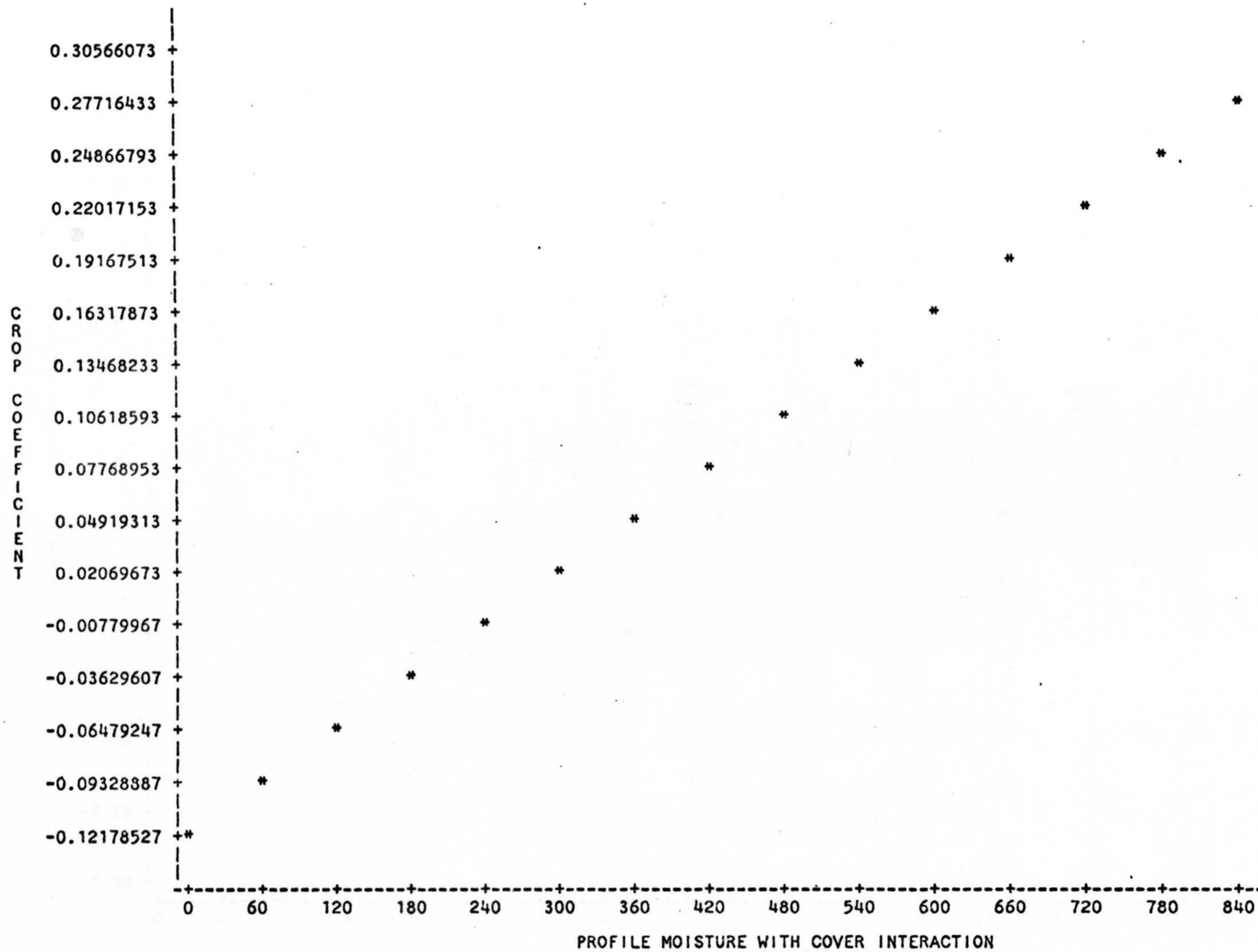
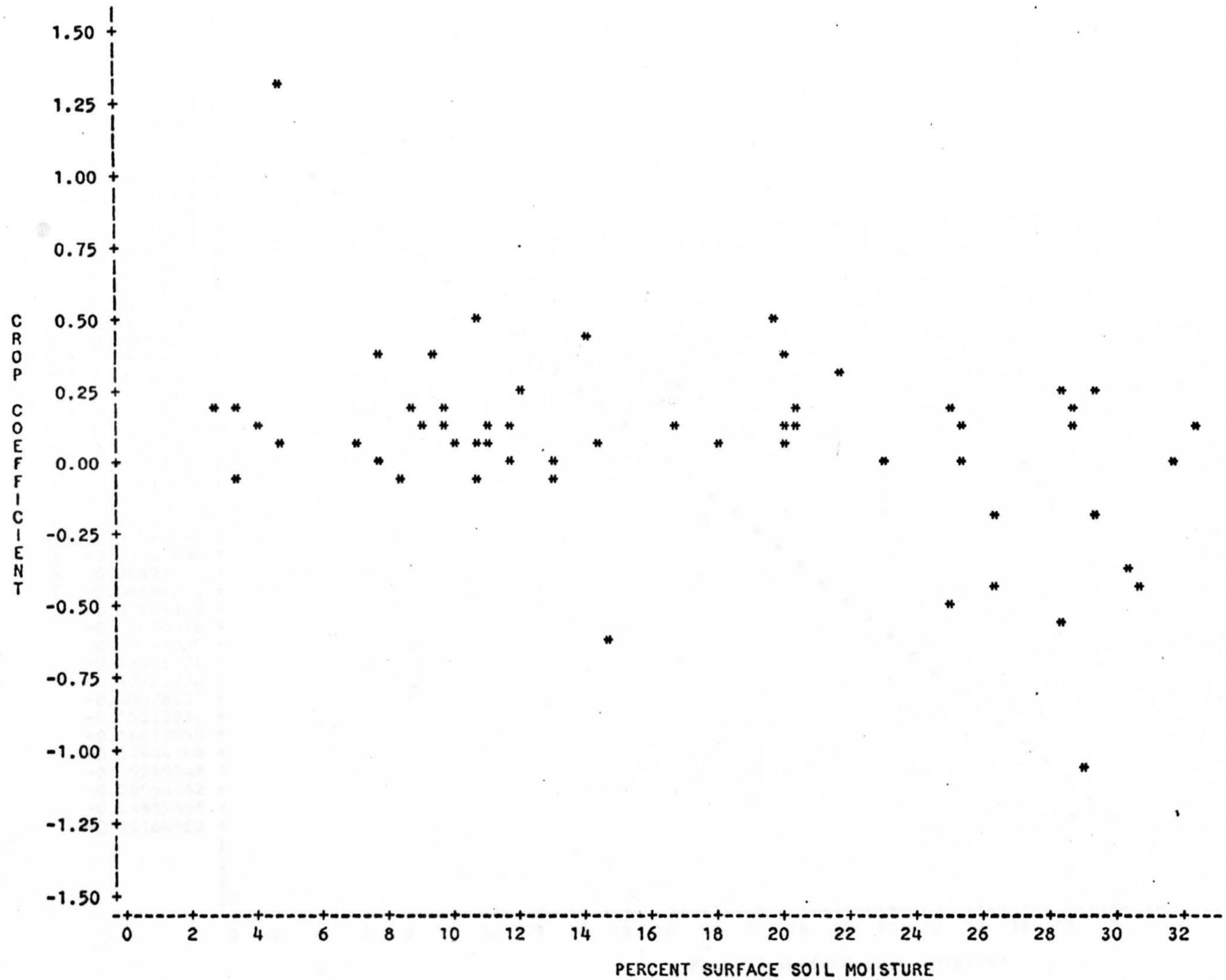


Figure 21

Figure 22

PLOT OF K VERSUS SURFACE MOISTURE (1979 GRAIN)

PLOT OF K*SURFACE SYMBOL USED IS *



PLOT OF K AS A FUNCTION OF SURFACE MOISTURE (1979 GRAIN)

PLOT OF K*SURFACE SYMBOL USED IS *

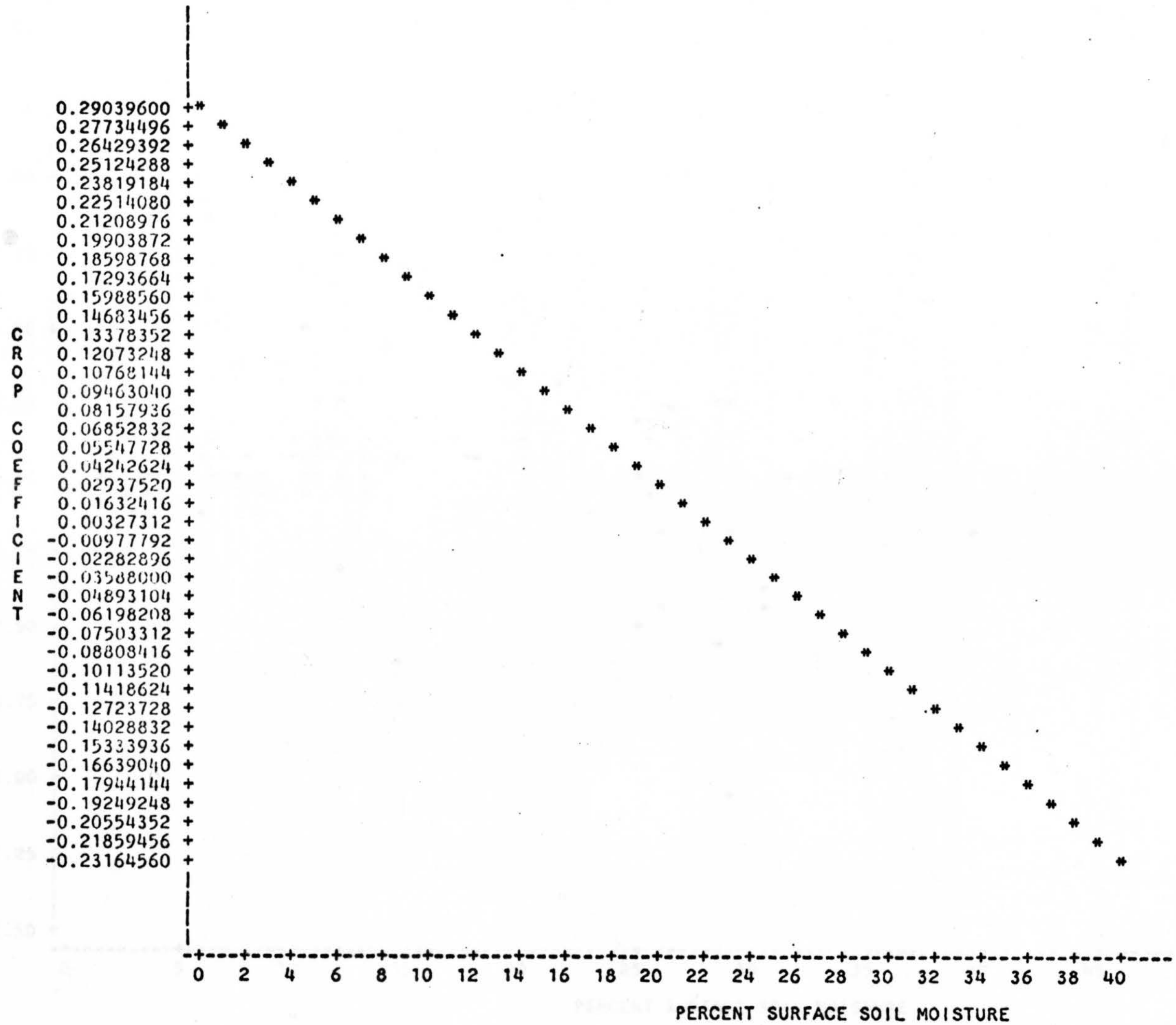


Figure 23

RESULTS FROM COMPLETE GRAIN DATA SET (1979-1980)

PLOT OF K*SURFACE SYMBOL USED IS *

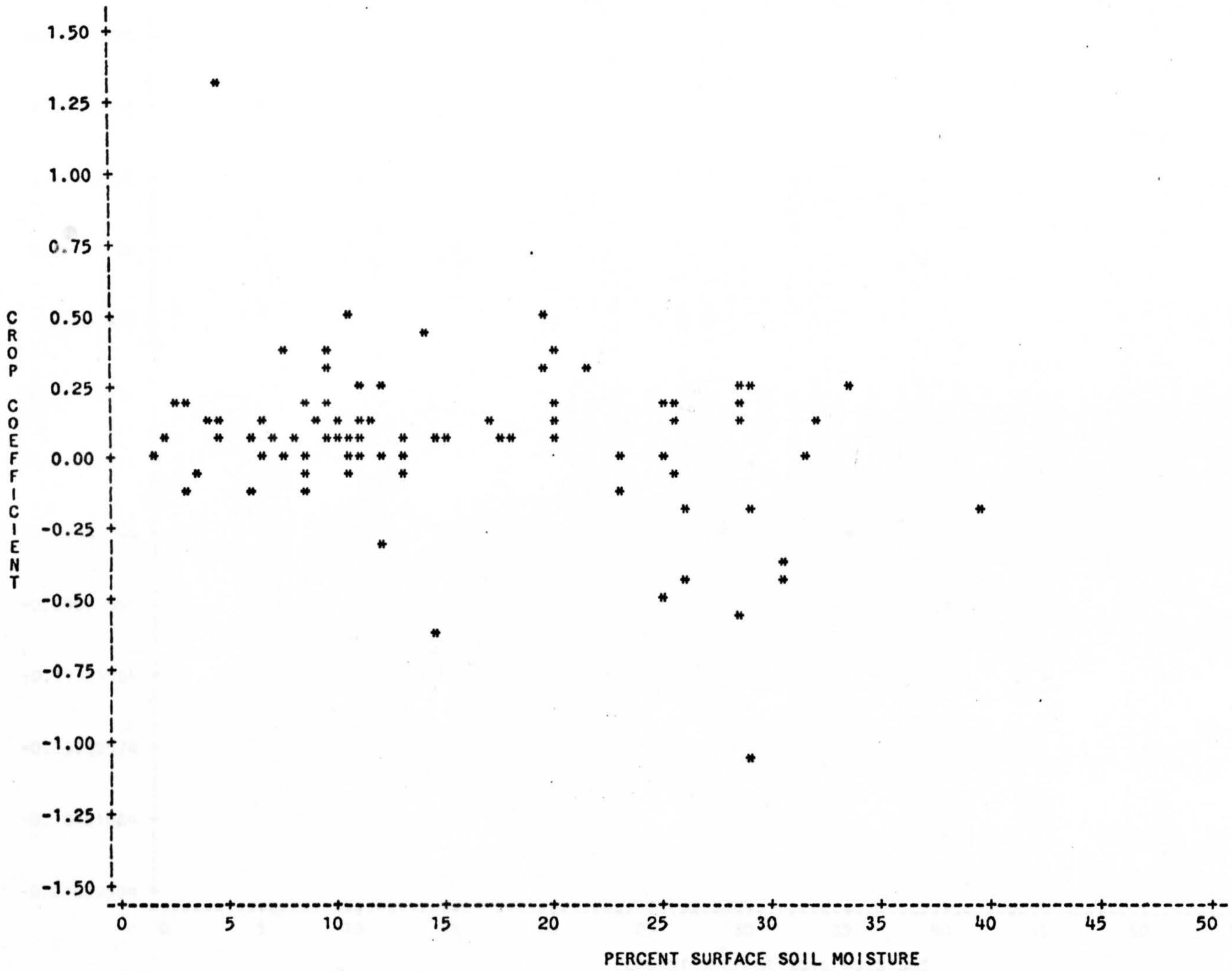


Figure 24

PLOT OF K AS A FUNCTION OF SURFACE MOISTURE (1979-80 GRAIN)

PLOT OF K*SURFACE SYMBOL USED IS *

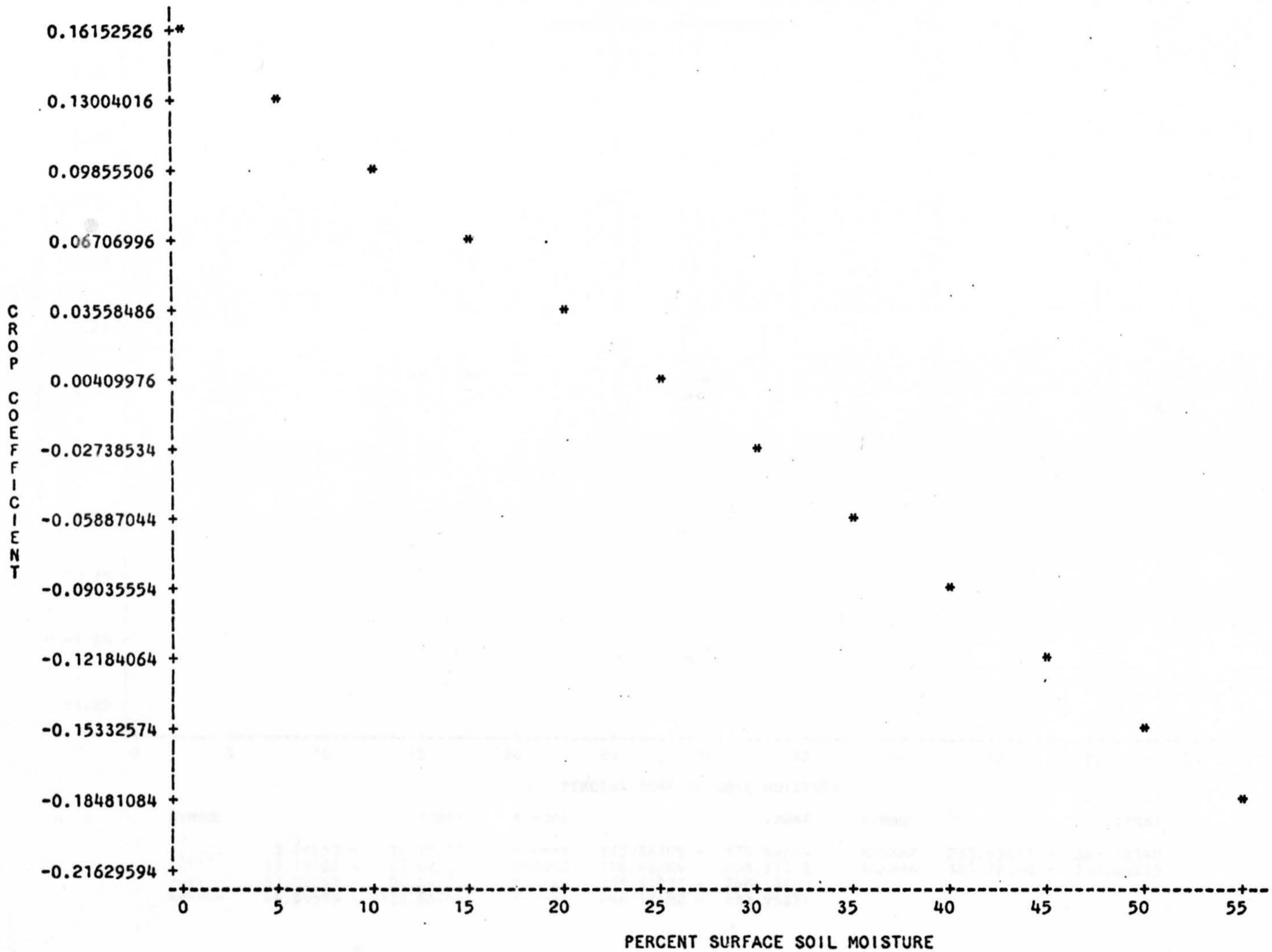
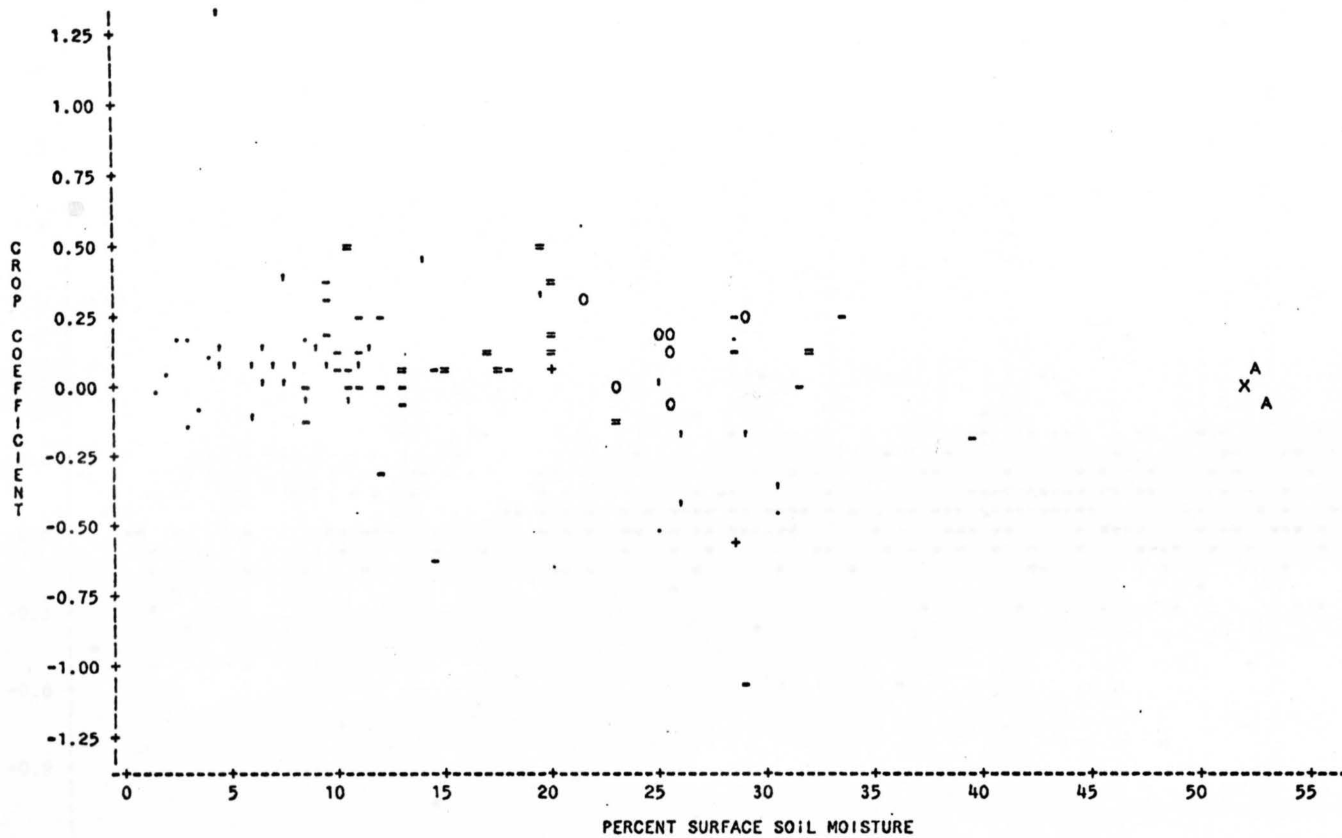


Figure 25

RESULTS FROM COMPLETE GRAIN DATA SET (1979-1980)

CONTOUR PLOT OF K*SURFACE



SYMBOL		IPRSF	SYMBOL		IPRSF	SYMBOL		IPRSF
iiiiii	0.28853 -	19.19988	++++++	132.66795 -	170.49064	XXXXXX	283.95871 -	321.78140
	19.19988 -	57.02257	000000	170.49064 -	208.31333	AAAAAA	321.78140 -	340.69275
------	57.02257 -	94.84526	XXXXXX	208.31333 -	246.13602			
======	94.84526 -	132.66795	------	246.13602 -	283.95871			

Figure 26: Contour Plot of k, Surface, and Profile/Surface Interacton.

RESULTS FROM COMPLETE DATA SET (1979-1980)

PLOT OF K*PROFILE   SYMBOL USED IS *

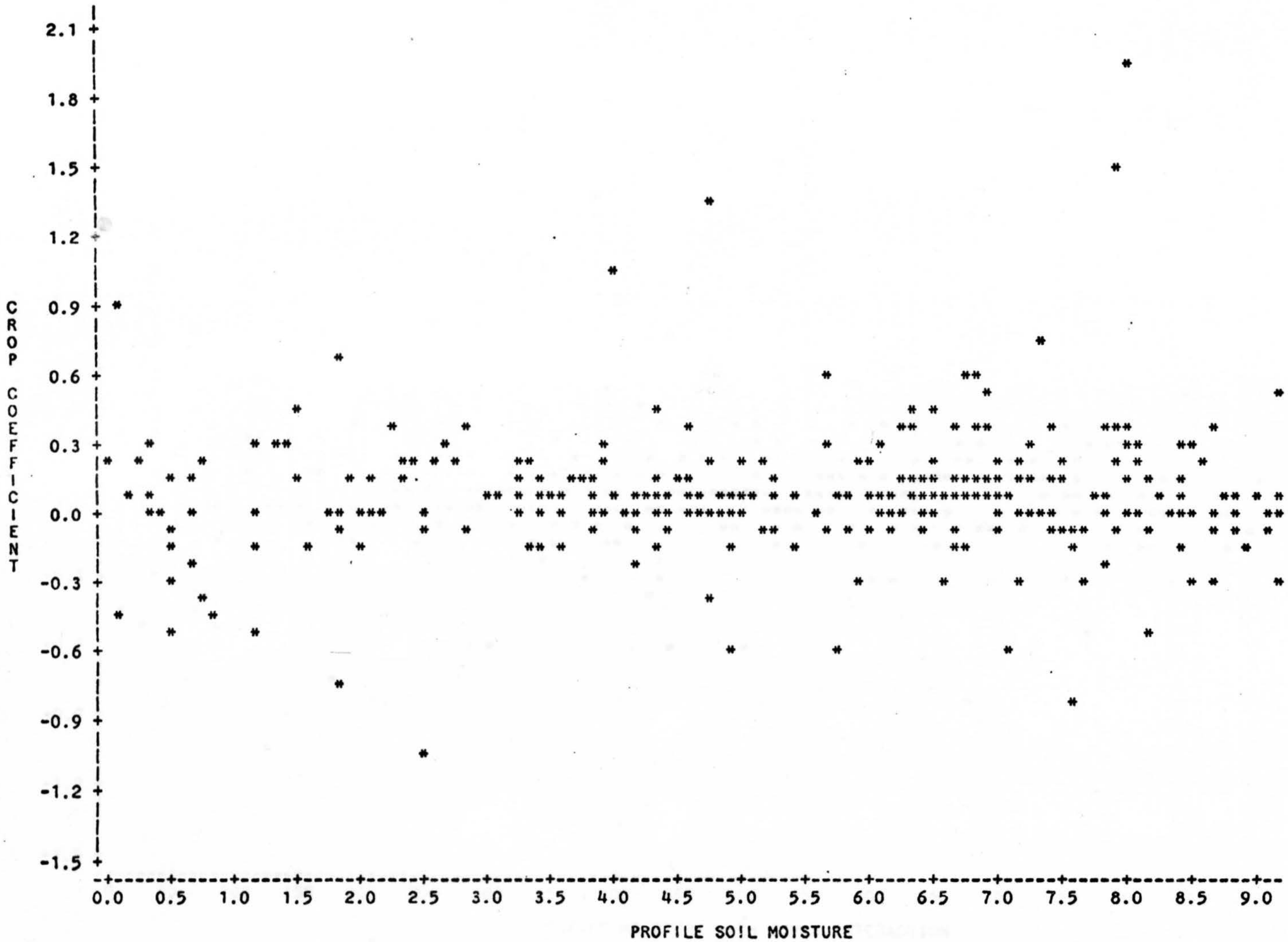


Figure 27

RESULTS FROM COMPLETE DATA SET (1979-1980)

PLOT OF K*IPRCOV SYMBOL USED IS *

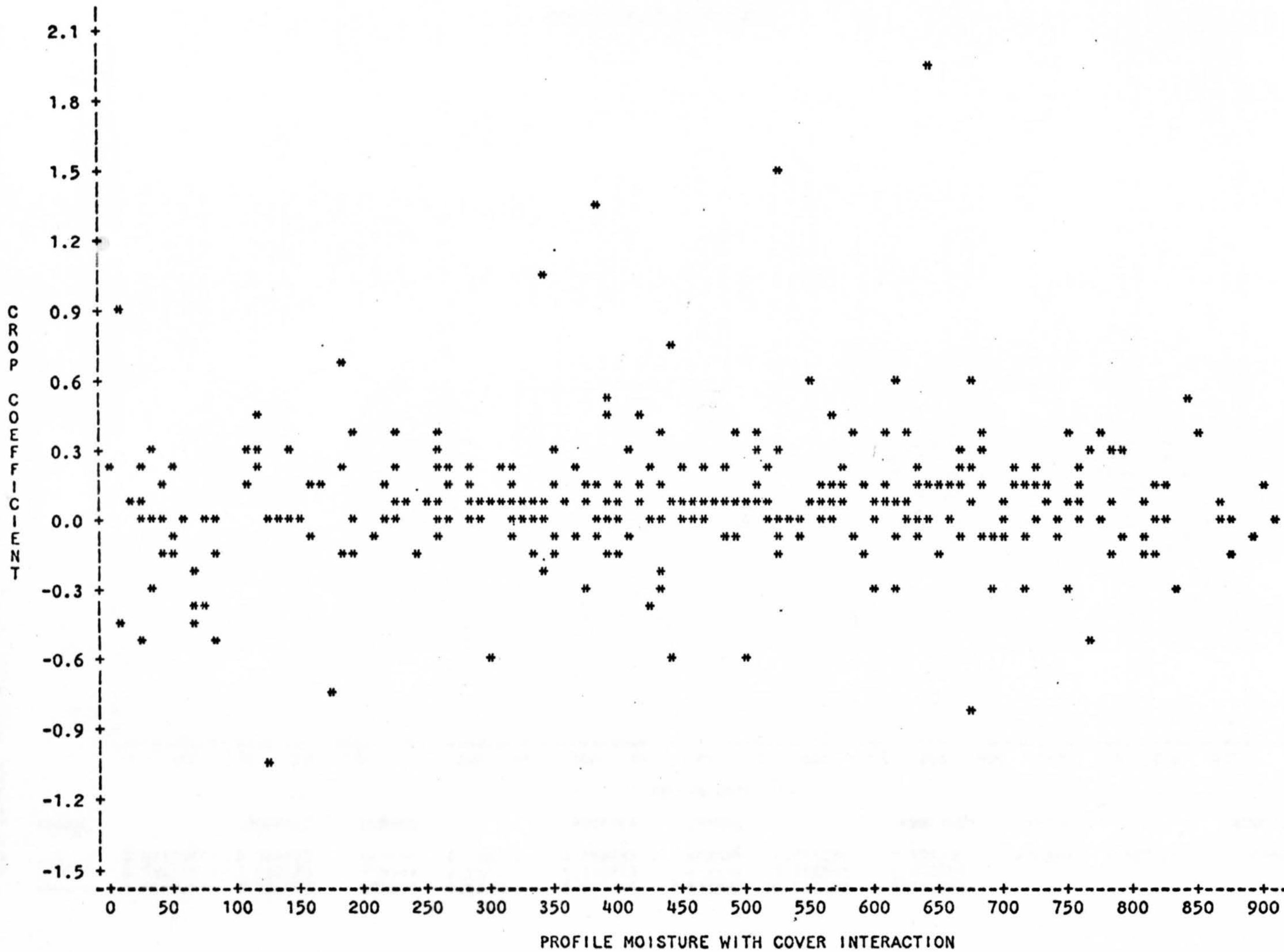
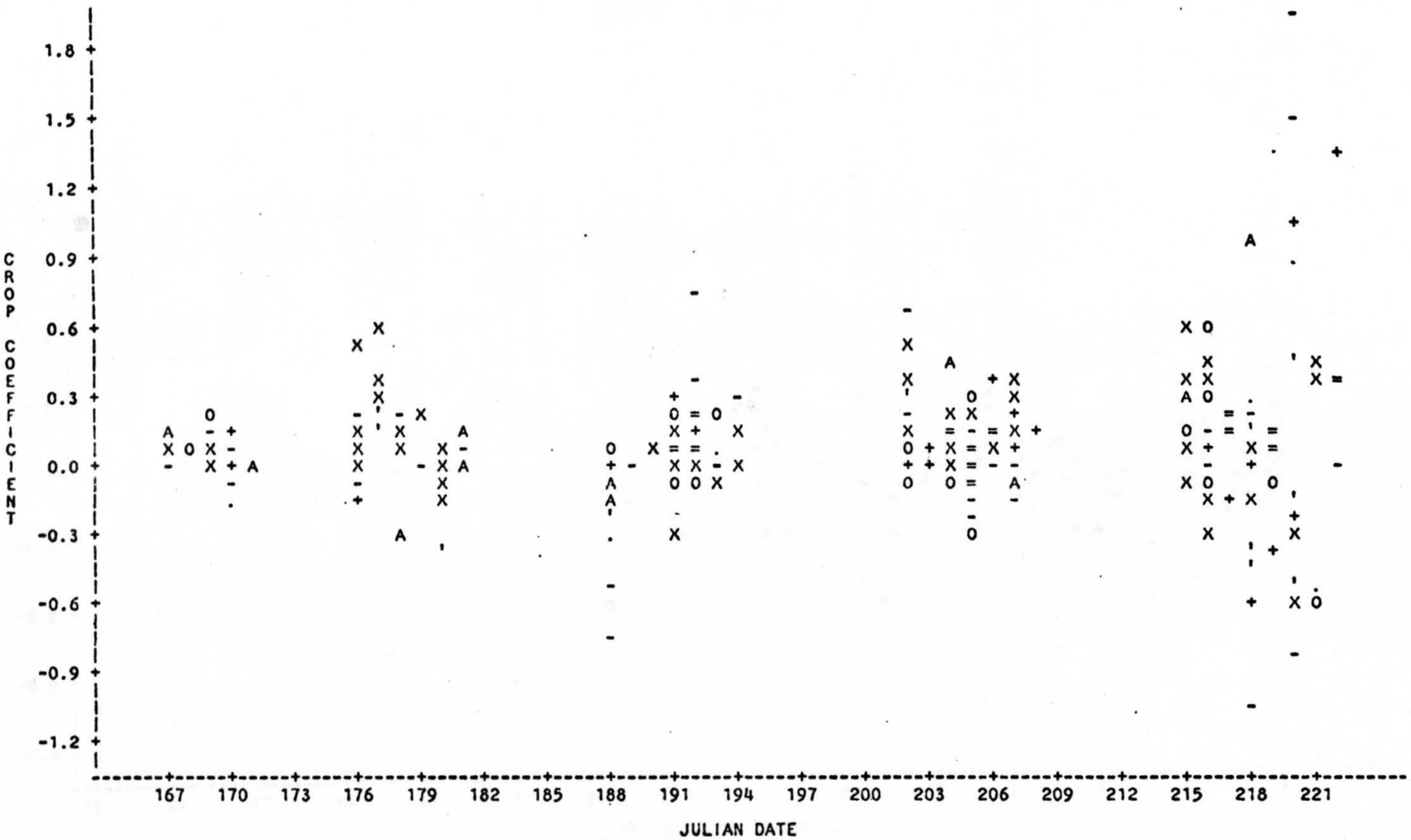


Figure 28

RESULTS FROM COMPLETE DATA SET (1979-1980)

CONTOUR PLOT OF K*JDATE

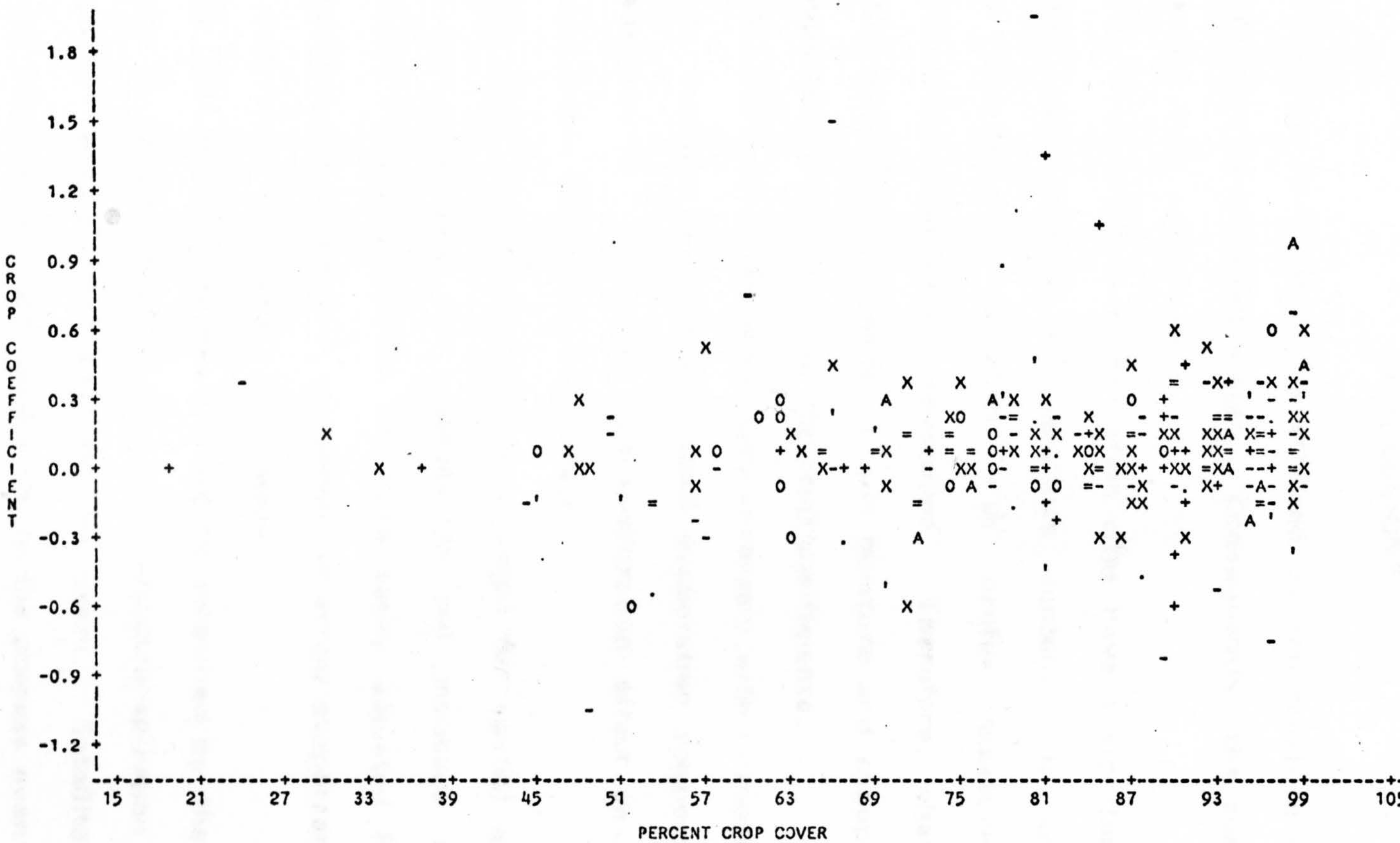


SYMBOL	PROFILE	SYMBOL	PROFILE	SYMBOL	PROFILE	SYMBOL	PROFILE
iiiiii	0.033550 - 0.584235	======	2.786975 - 3.888345	XXXXXX	6.091085 - 7.192455	AAAAAA	9.395195 - 9.945880
	0.584235 - 1.685605	++++++	3.888345 - 4.989715	------	7.192455 - 8.293825		
------	1.685605 - 2.786975	000000	4.989715 - 6.091085	XXXXXX	8.293825 - 9.395195		

Figure 29: Contour Plot of K, Julian Date, and Profile Moisture.

RESULTS FROM COMPLETE DATA SET (1979-1980)

CONTOUR PLOT OF K*COVER



SYMBOL	PROFILE	SYMBOL	PROFILE	SYMBOL	PROFILE	SYMBOL	PROFILE
''''''	0.033550 - 0.584235	======	2.786975 - 3.888345	XXXXXX	6.091085 - 7.192455	AAAAAA	9.395195 - 9.945880
''''''	0.584235 - 1.685605	++++++	3.888345 - 4.989715	------	7.192455 - 8.293825		
------	1.685605 - 2.786975	000000	4.989715 - 6.091085	XXXXXX	8.293825 - 9.395195		

Figure 30: Contour Plot of k, Percent Cover, and Profile Moisture.

CONCLUSIONS

1. Crop coefficients are affected by soil moisture conditions as well as canopy development stages. Consequently, the coefficients are not invariant from year to year.

2. Crop coefficients for grain sites have a significant negative correlation with surface soil moisture content. In addition, the k-values significantly correlate with profile moisture and soil moisture/percent crop cover interaction. Therefore, changes in the evaporation rate due to changes in soil moisture and canopy conditions is the apparent factor affecting the crop coefficients.

3. The crop coefficients vary inversely with evaporation rate.

4. Pasture sites have a small evaporation component of total evapotranspiration. Therefore, the evaporation effect on the pasture coefficients is too insignificant to detect.

5. Crop coefficients can be adjusted for spatial and temporal changes by accounting for changes in soil moisture and canopy development. The coefficients are more easily adjusted for the row crops in which the evaporation component of actual evapotranspiration is a major contributor throughout the season.

6. Soil moisture modeling could be simplified by the use of the coefficients to adjust potential to actual evapotranspiration rates over broad spatial regions (for any desired year). Satellite inputs of surface soil mosture and LAI could simplify the process even further.

Suggestions for Further Study

More study is needed to understand the factors affecting the crop coefficients for pasture or grass. By using a soil moisture model and calculating the evaporation and transpiration components of evapotranspiration separately a correlation with changing evaporation rate could possibly be detected.

By calculating the components separately, any correlation with evaporation (if it does exist) will not be obscured by the dominant transpiration component.

If the crop coefficients can be accurately predicted by surface soil moisture and LAI, adjustment to any region is possible. Actual evapotranspiration rates could be calculated daily and water balance calculations could predict daily soil moisture contents.

Actual soil moisture content could be checked every two weeks and calculated values compared to these measurements. If enough accuracy could be confirmed with this simple method, then eventually satellite data could be used for the surface soil moisture and LAI inputs to compute the coefficients. From the results of this study, row crops, small grains, and grasses would be the major crop divisions. The area in the satellite image could be averaged for these types of crops and daily profile soil moisture contents calculated (using the water budget approach).

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Appendix A

MAXR ANALYSIS RESULTS

RESULTS FROM 1979 DATA (GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE SURFACE ENTERED R SQUARE = 0.14349716 C(P) = 4.93294201

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.89783693	0.89783693	9.88	0.0026
ERROR	59	5.35899018	0.09083034		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.29039600				
SURFACE	-0.01305104	0.00415109	0.89783693	9.88	0.0026

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE PROFILE ENTERED R SQUARE = 0.19429818 C(P) = 3.25956673

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	1.21569010	0.60784505	6.99	0.0019
ERROR	58	5.04113701	0.08691616		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.12249073				
SURFACE	-0.01171507	0.00412032	0.70263486	8.08	0.0062
PROFILE	0.02979021	0.01557796	0.31785317	3.66	0.0608

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE COVER ENTERED R SQUARE = 0.22429576 C(P) = 3.09046866

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	1.40337980	0.46779327	5.49	0.0023
ERROR	57	4.85344731	0.08514820		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.18876502				
SURFACE	-0.01056472	0.00415115	0.55151288	6.48	0.0137
COVER	0.00374823	0.00252461	0.18768970	2.20	0.1431
PROFILE	0.02803289	0.01546408	0.27980994	3.29	0.0751

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE SURFACE ENTERED R SQUARE = 0.14349716 C(P) = 3.82422793

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.89783693	0.89783693	9.88	0.0026
ERROR	59	5.35899018	0.09083034		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.29039600				
SURFACE	-0.01305104	0.00415109	0.89783693	9.88	0.0026

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE COVER ENTERED R SQUARE = 0.17957502 C(P) = 3.26217222

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	1.12356986	0.56178493	6.35	0.0032
ERROR	58	5.13325725	0.08850444		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.06077888				
SURFACE	-0.01170700	0.00418312	0.69319451	7.83	0.0070
COVER	0.00409853	0.00256633	0.22573293	2.55	0.1157

STEP 2 SURFACE REPLACED BY ISFCOV R SQUARE = 0.19169556 C(P) = 2.40143671

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	1.19940598	0.59970299	6.88	0.0021
ERROR	58	5.05742113	0.08719692		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.32408917				
COVER	0.00743308	0.00257507	0.72654140	8.33	0.0055
ISFCOV	-0.00015196	0.00005117	0.76903063	8.82	0.0043

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE IPRCOV ENTERED R SQUARE = 0.10235268 C(P) = 2.81025727

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.64040304	0.64040304	6.73	0.0120
ERROR	59	5.61642407	0.09519363		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.12178527				
IPRCOV	0.00047494	0.00018311	0.64040304	6.73	0.0120

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE COVER ENTERED R SQUARE = 0.12147242 C(P) = 3.53630878

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.76003194	0.38001597	4.01	0.0234
ERROR	58	5.49679517	0.09477233		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.34237758				
COVER	0.00323629	0.00288052	0.11962889	1.26	0.2658
IPRCOV	0.00037732	0.00020231	0.32965658	3.48	0.0672

STEP 2 IPRCOV REPLACED BY PROFILE R SQUARE = 0.13614999 C(P) = 2.55834237

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.85186692	0.42593346	4.57	0.0143
ERROR	58	5.40496019	0.09318897		
TOTAL	60	6.25682711			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.49632977				
PROFILE	0.03400702	0.01599029	0.42149157	4.52	0.0377
COVER	0.00494750	0.00259471	0.33881168	3.64	0.0615

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

RESULTS FROM 1980 DATA (GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE IPRCOV ENTERED R SQUARE = 0.00887463 C(P) = 3.78474759

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.00502111	0.00502111	0.26	0.6142
ERROR	29	0.56076119	0.01933659		
TOTAL	30	0.56578230			
	B VALUE	**STD ERROR**	**TYPE II SS**	**F**	**PROB>F**
INTERCEPT	0.06987910				
IPRCOV	-0.00005970	0.00011716	0.00502111	0.26	0.6142

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE COVER ENTERED R SQUARE = 0.01929913 C(P) = 5.46095870

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.01091910	0.00545955	0.28	0.7612
ERROR	28	0.55486319	0.01981654		
TOTAL	30	0.56578230			
	B VALUE	**STD ERROR**	**TYPE II SS**	**F**	**PROB>F**
INTERCEPT	0.01437787				
COVER	0.00101391	0.00185850	0.00589799	0.30	0.5897
IPRCOV	-0.00010881	0.00014890	0.01058282	0.53	0.4710

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE PROFILE ENTERED R SQUARE = 0.13072586 C(P) = 4.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.07396238	0.02465413	1.35	0.2780
ERROR	27	0.49181992	0.01821555		
TOTAL	30	0.56578230			
	B VALUE	**STD ERROR**	**TYPE II SS**	**F**	**PROB>F**
INTERCEPT	-0.76308766				
PROFILE	0.17144609	0.09215722	0.06304328	3.46	0.0738
COVER	0.01011278	0.00520537	0.06875112	3.77	0.0625
IPRCOV	-0.00211858	0.00108970	0.06885223	3.78	0.0624

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

RESULTS FROM COMPLETE GRAIN DATA SET (1979-1980)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE SURFACE ENTERED R SQUARE = 0.06450520 C(P) = 9.86995687

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.44079924	0.44079924	6.21	0.0146
ERROR	90	6.39274649	0.07103052		
TOTAL	91	6.83354573			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.16152526				
SURFACE	-0.00629702	0.00252777	0.44079924	6.21	0.0146

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE IPRSF ENTERED R SQUARE = 0.12982918 C(P) = 5.03586762

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.88719363	0.44359681	6.64	0.0021
ERROR	89	5.94635210	0.06681294		
TOTAL	91	6.83354573			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.15122454				
SURFACE	-0.01264421	0.00346988	0.88718878	13.28	0.0005
IPRSF	0.00137853	0.00053332	0.44639439	6.68	0.0114

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE COVER ENTERED R SQUARE = 0.15618294 C(P) = 4.27877999

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	1.06728324	0.35576108	5.43	0.0019
ERROR	88	5.76626249	0.06552571		
TOTAL	91	6.83354573			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.07304324				
SURFACE	-0.01198299	0.00345936	0.78623217	12.00	0.0008
COVER	0.00281193	0.00169616	0.18008961	2.75	0.1009
IPRSF	0.00126724	0.00053240	0.37123232	5.67	0.0195

RESULTS FROM COMPLETE GRAIN DATA SET (1979-1980)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 3 SURFACE REPLACED BY ISFCOV R SQUARE = 0.16570725 C(P) = 3.28236191

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	1.13236805	0.37745602	5.83	0.0012
ERROR	88	5.70117767	0.06478611		
TOTAL	91	6.83354573			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.28154973				
COVER	0.00555918	0.00176994	0.63912358	9.87	0.0023
ISFCOV	-0.00016137	0.00004452	0.85131699	13.14	0.0005
IPRSF	0.00130440	0.00052624	0.39805005	6.14	0.0151

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE IPRCOV ENTERED R SQUARE = 0.18569058 C(P) = 3.19173744

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	1.26892510	0.31723128	4.96	0.0012
ERROR	87	5.56462063	0.06396116		
TOTAL	91	6.83354573			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.37843236				
COVER	0.00875823	0.00280824	0.62212898	9.73	0.0025
IPRCOV	-0.00036479	0.00024966	0.13655705	2.13	0.1476
ISFCOV	-0.00023818	0.00006870	0.76872400	12.02	0.0008
IPRSF	0.00245952	0.00094782	0.43068818	6.73	0.0111

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE SURFACE ENTERED R SQUARE = 0.18695366 C(P) = 5.05959678

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	1.27755637	0.25551127	3.96	0.0029
ERROR	86	5.55598936	0.06460453		
TOTAL	91	6.83354573			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.30609408				
SURFACE	-0.00460870	0.01260877	0.00863127	0.13	0.7156
COVER	0.00795750	0.00357276	0.32048484	4.96	0.0285
IPRCOV	-0.00038693	0.00025812	0.14517548	2.25	0.1375
ISFCOV	-0.00018560	0.00015959	0.08737572	1.35	0.2481
IPRSF	0.00255558	0.00098817	0.43209748	6.69	0.0114

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE IPRCOV ENTERED R SQUARE = 0.01800809 C(P) = 5.05977604

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.36363276	0.36363276	3.26	0.0725
ERROR	178	19.82910686	0.11139948		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.02912278				
IPRCOV	0.00018818	0.00010415	0.36363276	3.26	0.0725

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE COVER ENTERED R SQUARE = 0.02175295 C(P) = 6.36929999

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.43925156	0.21962578	1.97	0.1428
ERROR	177	19.75348806	0.11160163		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.07935276				
COVER	0.00148710	0.00180659	0.07561880	0.68	0.4115
IPRCOV	0.00015572	0.00011146	0.21783346	1.95	0.1641

STEP 2 IPRCOV REPLACED BY PROFILE R SQUARE = 0.02800680 C(P) = 5.21621298

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.56553408	0.28276704	2.55	0.0809
ERROR	177	19.62720553	0.11088817		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.17574968				
PROFILE	0.01634133	0.00927636	0.34411599	3.10	0.0799
COVER	0.00242368	0.00168451	0.22955483	2.07	0.1520

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE IPRCOV ENTERED R SQUARE = 0.01800809 C(P) = 7.25065391

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.36363276	0.36363276	3.26	0.0725
ERROR	178	19.82910686	0.11139948		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.02912278				
IPRCOV	0.00018818	0.00010415	0.36363276	3.26	0.0725

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE SURFACE ENTERED R SQUARE = 0.02513904 C(P) = 7.91993971

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.50762610	0.25381305	2.28	0.1051
ERROR	177	19.68511352	0.11121533		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.07034732				
SURFACE	-0.00265505	0.00233337	0.14399334	1.29	0.2567
IPRCOV	0.00019783	0.00010441	0.39923776	3.59	0.0598

STEP 2 IPRCOV REPLACED BY IPRSF R SQUARE = 0.04378112 C(P) = 4.44112043

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.88406066	0.44203033	4.05	0.0190
ERROR	177	19.30867896	0.10908858		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.16384787				
SURFACE	-0.00860303	0.00330148	0.74073708	6.79	0.0099
IPRSF	0.00103542	0.00038830	0.77567232	7.11	0.0084

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 3 VARIABLE ISFCOV ENTERED R SQUARE = 0.05952530 C(P) = 3.50308020

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	1.20197883	0.40065961	3.71	0.0127
ERROR	176	18.99076078	0.10790205		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.17330384				
SURFACE	-0.02011829	0.00746903	0.78285946	7.26	0.0078
IPRSF	0.00090334	0.00039378	0.56784515	5.26	0.0230
ISFCOV	0.00014017	0.00008166	0.31791818	2.95	0.0878

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE IPRCOV ENTERED R SQUARE = 0.06670016 C(P) = 4.16417077

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	1.34685896	0.33671474	3.13	0.0163
ERROR	175	18.84588066	0.10769075		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.27484968				
SURFACE	-0.02694339	0.00950274	0.86573645	8.04	0.0051
IPRSF	0.00153721	0.00067336	0.56123842	5.21	0.0236
IPRCOV	-0.00021990	0.00018959	0.14488013	1.35	0.2477
ISFCOV	0.00017844	0.00008800	0.44277831	4.11	0.0441

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE PROFILE ENTERED R SQUARE = 0.06896651 C(P) = 5.74124490

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	1.39262274	0.27852455	2.58	0.0279
ERROR	174	18.80011688	0.10804665		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.24166856				
SURFACE	-0.03018832	0.01074524	0.85281850	7.89	0.0055
PROFILE	0.02368630	0.03639501	0.04576378	0.42	0.5160
IPRSF	0.00129010	0.00077401	0.30016675	2.78	0.0974
IPRCOV	-0.00043713	0.00038403	0.13999557	1.30	0.2566
ISFCOV	0.00023502	0.00012380	0.38936373	3.60	0.0593

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 5 ISFCOV REPLACED BY COVER R SQUARE = 0.07002200 C(P) = 5.54427891

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	1.41393595	0.28278719	2.62	0.0258
ERROR	174	18.77880367	0.10792416		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.40045548				
SURFACE	-0.01081379	0.00505410	0.49406907	4.58	0.0338
COVER	0.00769724	0.00394589	0.41067694	3.81	0.0527
PROFILE	0.06487233	0.05277487	0.16307347	1.51	0.2206
IPRSF	0.00148636	0.00075727	0.41577474	3.85	0.0513
IPRCOV	-0.00095667	0.00060150	0.27300807	2.53	0.1135

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEP 6 VARIABLE ISFCOV ENTERED R SQUARE = 0.07293864 C(P) = 7.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	1.47283104	0.24547184	2.27	0.0392
ERROR	173	18.71990857	0.10820756		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.16144062				
SURFACE	-0.02121311	0.01497687	0.21708231	2.01	0.1585
COVER	0.00479790	0.00557275	0.08020830	0.74	0.3905
PROFILE	0.05769704	0.05373168	0.12476816	1.15	0.2844
IPRSF	0.00135653	0.00077842	0.32861427	3.04	0.0832
IPRCOV	-0.00085399	0.00061816	0.20651722	1.91	0.1689
ISFCOV	0.00012892	0.00017474	0.05889509	0.54	0.4617

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE COVER ENTERED R SQUARE = 0.01096523 C(P) = 4.42338026

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.22141810	0.22141810	1.97	0.1618
ERROR	178	19.97132152	0.11219844		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.08322583				
COVER	0.00238008	0.00169425	0.22141810	1.97	0.1618

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE SURFACE ENTERED R SQUARE = 0.01746963 C(P) = 5.23682469

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.35275963	0.17637981	1.57	0.2102
ERROR	177	19.83997999	0.11209028		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.05019789				
SURFACE	-0.00253333	0.00234032	0.13134153	1.17	0.2805
COVER	0.00250633	0.00169745	0.24437129	2.18	0.1416

STEP 2 COVER REPLACED BY ISFCOV R SQUARE = 0.03140404 C(P) = 2.69485676

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.63413368	0.31706684	2.87	0.0594
ERROR	177	19.55860593	0.11050060		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.16680017				
SURFACE	-0.01783339	0.00749092	0.62627043	5.67	0.0183
ISFCOV	0.00017678	0.00008105	0.52574535	4.76	0.0305

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE COVER ENTERED R SQUARE = 0.01096523 C(P) = 4.42338026

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.22141810	0.22141810	1.97	0.1618
ERROR	178	19.97132152	0.11219844		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.08322583				
COVER	0.00238008	0.00169425	0.22141810	1.97	0.1618

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE SURFACE ENTERED R SQUARE = 0.01746963 C(P) = 5.23682469

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.35275963	0.17637981	1.57	0.2102
ERROR	177	19.83997999	0.11209028		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.05019789				
SURFACE	-0.00253333	0.00234032	0.13134153	1.17	0.2805
COVER	0.00250633	0.00169745	0.24437129	2.18	0.1416

STEP 2 COVER REPLACED BY ISFCOV R SQUARE = 0.03140404 C(P) = 2.69485676

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.63413368	0.31706684	2.87	0.0594
ERROR	177	19.55860593	0.11050060		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.16680017				
SURFACE	-0.01783339	0.00749092	0.62627043	5.67	0.0183
ISFCOV	0.00017678	0.00008105	0.52574535	4.76	0.0305

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

RESULTS FROM 1979 DATA (PASTURE AND GRAIN)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 3 VARIABLE PROFILE ENTERED R SQUARE = 0.04547372 C(P) = 3.14452100

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.91823901	0.30607967	2.79	0.0411
ERROR	176	19.27450060	0.10951421		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.08677427				
SURFACE	-0.01702281	0.00747437	0.56804602	5.19	0.0240
PROFILE	0.01490088	0.00925140	0.28410533	2.59	0.1090
ISFCOV	0.00016633	0.00008095	0.46240543	4.22	0.0414

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE IPRCOV ENTERED R SQUARE = 0.05410142 C(P) = 3.56143727

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	1.09245599	0.27311400	2.50	0.0441
ERROR	175	19.10028363	0.10914448		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.09420229				
SURFACE	-0.02647164	0.01056459	0.68526449	6.28	0.0131
PROFILE	0.05344514	0.03187545	0.30683544	2.81	0.0954
IPRCOV	-0.00048621	0.00038484	0.17421697	1.60	0.2081
ISFCOV	0.00028069	0.00012134	0.58404050	5.35	0.0219

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE COVER ENTERED R SQUARE = 0.05666476 C(P) = 5.09109466

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	1.14421678	0.22884336	2.09	0.0681
ERROR	174	19.04852284	0.10947427		
TOTAL	179	20.19273962			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.23410015				
SURFACE	-0.01914417	0.01501687	0.17792068	1.63	0.2041
COVER	0.00383528	0.00557767	0.05176079	0.47	0.4926
PROFILE	0.08185714	0.05221527	0.26904826	2.46	0.1188
IPRCOV	-0.00082145	0.00062149	0.19125322	1.75	0.1880
ISFCOV	0.00019776	0.00017121	0.14605556	1.33	0.2497

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

RESULTS FROM COMPLETE DATA SET (1979-1980)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 1 VARIABLE PROFILE ENTERED R SQUARE = 0.00776173 C(P) = 13.97380516

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.19411309	0.19411309	2.54	0.1118
ERROR	325	24.81489787	0.07635353		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.02495764				
PROFILE	0.00952902	0.00597634	0.19411309	2.54	0.1118

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE COVER ENTERED R SQUARE = 0.01190073 C(P) = 14.56815982

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.29762543	0.14881271	1.95	0.1438
ERROR	324	24.71138554	0.07626971		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.07416078				
COVER	0.00121045	0.00103903	0.10351234	1.36	0.2449
PROFILE	0.00918992	0.00598015	0.18011570	2.36	0.1253

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE IPRCOV ENTERED R SQUARE = 0.02679783 C(P) = 11.50895748

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.67018729	0.22339576	2.96	0.0318
ERROR	323	24.33882367	0.07535240		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.52146751				
COVER	0.00657467	0.00262420	0.47298793	6.28	0.0127
PROFILE	0.08728117	0.03561924	0.45244813	6.00	0.0148
IPRCOV	-0.00093288	0.00041954	0.37256187	4.94	0.0269

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

RESULTS FROM COMPLETE DATA SET (1979-1980)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 4 VARIABLE SURFACE ENTERED R SQUARE = 0.03060226 C(P) = 12.21693780

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.76533218	0.19133305	2.54	0.0398
ERROR	322	24.24367878	0.07529093		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.50569596				
SURFACE	-0.00133304	0.00118583	0.09514489	1.26	0.2618
COVER	0.00665324	0.00262406	0.48401798	6.43	0.0117
PROFILE	0.08589003	0.03562621	0.43761160	5.81	0.0165
IPRCOV	-0.00091605	0.00041964	0.35878808	4.77	0.0298

STEP 4 PROFILE REPLACED BY IPRSF R SQUARE = 0.04472453 C(P) = 7.42087488

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	1.11851635	0.27962909	3.77	0.0052
ERROR	322	23.89049461	0.07419408		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.01276522				
SURFACE	-0.00846632	0.00245480	0.88252362	11.89	0.0006
COVER	0.00262474	0.00123886	0.33303979	4.49	0.0349
IPRCOV	-0.00023214	0.00011855	0.28449532	3.83	0.0511
IPRSF	0.00130860	0.00040083	0.79079577	10.66	0.0012

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE PROFILE ENTERED R SQUARE = 0.05913152 C(P) = 4.52812109

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	1.47882087	0.29576417	4.03	0.0016
ERROR	321	23.53019009	0.07330277		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.45922289				
SURFACE	-0.00804004	0.00244758	0.79097789	10.79	0.0011
COVER	0.00773220	0.00261218	0.64227430	8.76	0.0033
PROFILE	0.07812997	0.03524058	0.36030452	4.92	0.0273
IPRCOV	-0.00112456	0.00041942	0.52697471	7.19	0.0077
IPRSF	0.00124610	0.00039941	0.71348869	9.73	0.0020

RESULTS FROM COMPLETE DATA SET (1979-1980)

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE K

STEP 5 IPRSF REPLACED BY IPSCOV R SQUARE = 0.06049463 C(P) = 4.06519449

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	1.51291099	0.30258220	4.13	0.0013
ERROR	321	23.49609998	0.07319657		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.49105182				
SURFACE	-0.00754481	0.00226828	0.80983029	11.06	0.0010
COVER	0.00800052	0.00262143	0.68179130	9.31	0.0025
PROFILE	0.10031777	0.03541613	0.58727869	8.02	0.0049
IPRCOV	-0.00136424	0.00043688	0.71375265	9.75	0.0020
IPSCOV	0.00001322	0.00000414	0.74757880	10.21	0.0015

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEP 6 VARIABLE IPRSF ENTERED R SQUARE = 0.06064316 C(P) = 6.01475490

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	1.51662538	0.25277090	3.44	0.0026
ERROR	320	23.49238558	0.07341370		
TOTAL	326	25.00901096			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.48295708				
SURFACE	-0.00776785	0.00247862	0.72103699	9.82	0.0019
COVER	0.00795615	0.00263272	0.67046232	9.13	0.0027
PROFILE	0.09507469	0.04244233	0.36839059	5.02	0.0258
IPRCOV	-0.00131235	0.00049463	0.51678969	7.04	0.0084
IPRSF	0.00030761	0.00136754	0.00371439	0.05	0.8222
IPSCOV	0.00001017	0.00001418	0.03780451	0.51	0.4735

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

Appendix B

RAW DATA USED IN STATISTICAL ANALYSIS

RESULTS FROM 1979 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
1	176	0.0155	23.0	90	8.44270	2070.0	759.843
1	191	0.1539	25.3	93	7.02575	2352.9	653.395
1	218	-0.4670	26.2	81	0.85966	2122.2	69.632
3	191	-0.0009	13.0	91	6.23978	1183.0	567.820
3	218	-0.1726	39.6	87	6.75627	3445.2	587.795
6	176	0.5183	10.5	92	9.14012	966.0	840.891
6	191	0.0719	11.1	94	3.01842	1043.4	283.731
6	218	-0.3666	30.4	98	0.73420	2979.2	71.952
8	176	0.1965	17.5	90	7.53497	1575.0	678.147
8	191	0.2840	29.2	89	3.94091	2598.8	350.741
9	176	0.2097	8.6	97	0.03355	834.2	3.254
9	191	0.1304	10.9	93	7.21214	1013.7	670.729
9	218	-0.4560	30.5	88	0.09699	2684.0	8.535
10	191	0.2247	12.0	97	5.00408	1164.0	485.396
10	218	-0.5733	28.4	90	4.94457	2556.0	445.011
11	176	-0.0027	31.7	86	8.65034	2726.2	743.929
11	191	0.2550	29.2	75	6.00659	2190.0	450.494
11	218	-0.1789	29.2	51	1.56058	1489.2	79.590
12	176	0.1803	9.5	90	6.72218	855.0	604.996
12	191	-0.0510	8.3	62	5.63471	514.6	349.352
12	218	-1.0632	29.1	49	2.51170	1425.9	123.073
15	177	0.3945	9.4	71	6.90758	667.4	490.438
15	191	0.0887	18.1	76	3.25710	1375.6	247.540
15	218	0.1670	28.6	69	0.62575	1973.4	43.177
18	177	0.5943	12.2	90	6.82298	1098.0	614.068
18	191	0.0835	5.4	96	3.38822	518.4	325.269
18	218	-0.1680	17.8	87	9.27215	1548.6	806.677
21	177	0.3336	21.5	81	8.40500	1741.5	680.805
21	191	0.1468	11.7	96	3.65472	1123.2	350.853
21	218	0.2520	28.3	78	2.30505	2207.4	179.794
23	191	0.1956	5.0	88	2.59037	440.0	227.953
23	204	-0.1097	6.6	82	6.01100	541.2	492.902
25	204	0.1217	1.7	74	3.84498	125.8	284.529
25	219	0.1310	11.2	71	3.75641	795.2	266.705
26	192	0.1725	2.5	84	4.57919	210.0	384.652
26	205	0.0553	7.1	65	3.55679	461.5	231.191
26	219	0.0952	11.6	74	3.46079	858.4	256.098
28	192	0.1942	3.2	94	3.88319	300.8	365.020
28	205	-0.0385	3.4	84	3.80159	285.6	319.334
28	219	-0.0466	10.7	74	5.21279	791.8	385.746
31	192	0.0768	2.7	98	3.10559	264.6	304.348
31	205	-0.0018	5.7	98	3.41279	558.6	334.453
31	219	-0.3996	15.7	90	4.74239	1413.0	426.815
33	192	0.2505	4.3	93	3.35039	399.9	311.586
33	205	0.1155	3.7	93	2.31840	344.1	215.611
33	219	-0.0884	7.0	85	2.47200	595.0	210.120
38	192	-0.0396	7.3	80	5.14559	584.0	411.647
38	205	0.0363	13.2	75	6.12479	990.0	459.359
38	220	-0.2642	18.5	91	6.55679	1683.5	596.668
39	192	0.0869	1.3	69	3.80159	89.7	262.310
39	205	-0.1968	4.2	56	7.79519	235.2	436.531
40	192	0.3893	3.1	24	7.96445	74.4	191.147
40	205	-0.1625	18.4	44	7.56755	809.6	332.972
40	220	-0.5543	27.4	70	1.18375	1918.0	82.862
43	178	-0.2851	12.9	72	9.60938	928.8	691.875
43	192	0.7297	14.4	60	7.33382	864.0	440.029

RESULTS FROM 1979 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
43	205	-0.31380	27.1	63	5.92703	1707.3	373.403
43	220	1.51083	21.4	66	7.91594	1412.4	522.452
44	178	0.04206	7.4	96	9.03608	710.4	867.464
44	205	-0.02932	9.0	91	0.67219	819.0	61.169
44	220	0.88766	12.2	78	0.09447	951.6	7.369
45	179	0.19672	3.2	84	8.58626	268.8	721.246
45	193	-0.10859	8.1	70	8.81557	567.0	617.090
48	179	-0.02724	25.2	95	1.98637	2394.0	188.705
48	206	0.11468	32.2	87	3.26968	2801.4	284.462
48	220	0.44076	14.0	80	1.51009	1120.0	120.807
49	180	-0.07897	16.1	92	6.69437	1481.2	615.882
49	207	0.40381	14.6	75	6.81344	1095.0	511.008
49	220	-0.25298	9.9	82	4.14980	811.8	340.284
52	180	-0.00072	8.4	90	9.04931	756.0	814.438
52	193	0.05256	9.6	82	0.30615	787.2	25.104
52	220	1.01927	5.7	85	4.01309	484.5	341.113
53	180	-0.12061	7.3	88	8.90378	642.4	783.533
53	193	-0.00982	15.8	75	1.75705	1185.0	131.779
53	220	-0.57784	15.1	71	7.05158	1072.1	500.662
55	193	-0.07279	19.6	56	8.67004	1097.6	485.522
55	207	0.26613	22.5	48	8.48483	1080.0	407.272
55	220	-0.81937	20.7	89	7.58078	1842.3	674.689
56	180	-0.04001	58.0	88	9.21689	5104.0	811.086
56	194	0.30583	14.2	98	8.10116	1391.6	793.914
56	207	0.22459	14.9	97	4.77161	1445.3	462.846
56	220	0.42383	10.5	91	4.29533	955.5	390.875
57	180	-0.39818	14.5	90	0.77361	1305.0	69.625
57	207	0.23880	18.9	80	0.26205	1512.0	20.964
57	220	1.94019	13.7	80	7.97327	1096.0	637.862
59	207	0.22570	33.3	50	2.38326	1665.0	119.163
59	220	-0.18582	26.2	45	1.18816	1179.0	53.467
61	207	0.14602	28.6	30	9.39481	858.0	281.844
61	221	-0.52010	25.1	53	0.50307	1330.3	26.663
62	207	0.10771	20.2	95	4.90256	1919.0	465.743
62	221	-0.61548	14.6	52	5.72318	759.2	297.605
64	207	0.15810	20.2	89	6.27308	1797.8	558.304
64	221	0.48206	19.5	66	6.37460	1287.0	420.724
66	207	0.16076	25.0	92	7.03871	2300.0	647.561
66	221	0.38014	20.0	93	6.27731	1860.0	583.790
68	207	0.14892	16.8	93	6.36614	1562.4	592.051
68	222	1.32961	4.5	81	4.74182	364.5	384.087
72	208	0.15310	19.9	97	4.47965	1930.3	434.526
72	222	0.38656	7.6	90	2.84130	684.0	255.717
73	222	0.01167	11.8	58	8.03312	684.4	465.921
74	176	-0.03275	13.0	77	4.99985	1001.0	384.988
74	191	0.08193	10.8	84	5.80355	907.2	487.498
74	204	0.05465	14.3	79	6.36614	1129.7	502.925
74	215	0.07164	20.1	85	6.75107	1708.5	573.841
75	176	0.09365	17.7	83	8.87029	1469.1	736.234
75	191	0.19642	9.3	95	7.94393	883.5	754.673
75	204	0.25845	11.1	99	7.18253	1098.9	711.070
75	215	-0.04670	15.3	98	7.01333	1499.4	687.306
76	176	-0.13237	12.6	81	4.88141	1020.6	395.394
76	191	0.16583	19.3	97	6.49304	1872.1	629.825
76	204	0.13320	14.6	97	6.52265	1416.2	632.697
76	215	0.36635	13.7	97	6.25616	1328.9	606.848

RESULTS FROM 1979 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
77	176	0.02299	7.7	81	4.10732	623.7	332.693
77	191	0.06259	4.7	81	4.22153	380.7	341.944
77	204	0.10051	3.9	73	4.61069	284.7	336.580
77	215	0.14816	9.1	77	5.24519	700.7	403.880
78	176	-0.01335	29.5	86	0.35467	2537.0	30.502
78	191	0.33576	29.7	99	1.19257	2940.3	118.064
78	204	0.45706	26.4	99	9.58292	2613.6	948.709
78	215	0.58276	21.7	99	6.79139	2148.3	672.348
79	176	-0.08666	39.7	87	1.81438	3453.9	157.851
79	191	0.11250	28.2	95	3.08005	2679.0	292.605
79	204	0.21210	19.8	96	2.78458	1900.8	267.320
79	215	0.36951	27.2	99	2.23333	2692.8	221.100
80	177	0.14423	18.4	74	1.50568	1361.6	111.420
80	191	0.12920	11.7	93	9.92249	1088.1	922.792
80	204	0.16661	13.6	69	9.70199	938.4	669.437
80	215	0.29569	21.1	70	9.77695	1477.0	684.386
81	177	0.13896	11.8	50	7.50140	590.0	375.070
81	191	0.06910	7.4	70	7.05599	518.0	493.919
81	204	0.21793	6.9	74	6.96338	510.6	515.290
81	215	0.08378	10.0	47	7.10891	470.0	334.119
82	177	0.20629	21.6	66	0.75597	1425.6	49.894
82	192	0.14936	24.4	77	9.35360	1878.8	720.227
82	205	0.17278	22.6	90	8.18935	2034.0	737.041
82	216	0.47565	18.5	87	6.51797	1609.5	567.063
85	178	0.22171	30.2	82	8.10557	2476.4	664.657
85	192	0.12818	13.0	99	6.91928	1287.0	685.009
85	205	0.26094	17.3	98	6.46505	1695.4	633.575
85	216	0.63083	25.0	97	5.63597	2425.0	546.689
86	178	0.18475	17.0	80	6.31952	1360.0	505.562
86	192	-0.02582	13.3	93	6.40772	1236.9	595.918
86	205	0.10325	15.0	93	6.50033	1395.0	604.531
88	192	0.02833	4.3	81	1.82133	348.3	147.528
88	205	0.15570	3.6	79	2.10357	284.4	166.182
89	178	0.10050	16.5	64	6.13430	1056.0	392.595
89	192	-0.00931	16.7	65	6.14753	1085.5	399.589
89	205	0.13138	18.4	63	6.40772	1159.2	403.686
89	216	0.29555	13.1	62	5.65361	812.2	350.524
90	178	0.12107	16.3	82	6.84959	1336.6	561.666
90	192	-0.06295	14.2	92	6.67679	1306.4	614.265
90	205	0.26529	13.0	87	6.04319	1131.0	525.758
90	216	0.06327	4.6	91	4.86719	418.6	442.914
91	178	0.21038	12.7	89	4.76639	1130.3	424.209
91	192	0.01429	15.0	92	3.55199	1380.0	326.783
91	205	0.22846	13.5	88	3.21599	1188.0	283.007
91	216	0.18690	50.8	83	1.89120	4216.4	156.970
98	180	0.10138	17.5	87	6.98147	1522.5	607.388
98	193	0.19560	11.3	97	5.91722	1096.1	573.970
98	206	0.36305	10.4	94	4.56659	977.6	429.259
98	217	0.11725	13.4	93	3.41334	1246.2	317.441
99	180	0.08791	37.9	89	5.71218	3373.1	508.384
99	194	0.31085	29.3	97	2.68198	2842.1	260.152
99	207	-0.16098	25.0	97	2.00473	2425.0	194.459
99	218	0.00488	33.9	98	4.06744	3322.2	398.609
100	180	0.08785	9.9	81	8.28403	801.9	671.006
100	194	0.11815	9.8	85	6.79697	833.0	577.742
100	207	-0.00399	11.8	86	7.37999	1014.8	634.679

RESULTS FROM 1979 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
100	218	0.10592	11.7	96	8.44270	1123.2	810.499
103	181	0.15173	20.8	79	9.59768	1643.2	758.217
103	194	0.02183	16.3	99	8.83753	1613.7	874.915
103	207	-0.05703	17.4	98	9.88918	1705.2	969.140
103	218	0.26706	19.9	97	0.36150	1930.3	35.065
105	181	0.01365	36.4	99	9.81170	3603.6	971.358
105	207	-0.05160	63.9	98	9.12167	6262.2	893.924
105	218	0.95082	67.2	98	9.60136	6585.6	940.933
106	181	0.05392	21.0	97	7.81910	2037.0	758.453
106	194	0.16388	27.3	99	7.13645	2702.7	706.509
106	207	-0.08887	21.6	99	7.50545	2138.4	743.040
106	218	-0.12470	12.4	97	8.44270	1202.8	818.942

RESULTS FROM 1980 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
2	167	0.13293	16.1	94	9.54971	1513.4	897.673
2	188	-0.18906	54.1	97	0.66039	5247.7	64.058
2	202	0.37832	48.8	98	8.66042	4782.4	848.721
2	216	-0.05116	26.3	98	5.99255	2577.4	587.270
4	167	0.03257	30.1	96	8.09953	2889.6	777.555
4	188	-0.09733	64.3	96	9.75266	6172.8	936.255
4	202	0.35884	59.6	98	7.90766	5840.8	774.951
4	216	-0.16301	37.4	98	6.63461	3665.2	650.192
7	167	0.09090	10.5	91	6.85970	955.5	624.233
7	188	-0.08845	25.4	90	7.92611	2286.0	713.350
7	202	0.21063	25.6	94	7.50914	2406.4	705.859
7	216	0.03946	17.3	92	6.09218	1591.6	560.481
8	167	0.14887	44.8	95	6.76376	4256.0	642.557
8	188	-0.75874	78.1	97	1.84119	7575.7	178.595
8	202	0.64399	54.3	98	1.86333	5321.4	182.606
8	216	-0.09277	17.8	95	7.39475	1691.0	702.501
9	167	0.03574	11.0	91	2.11047	1001.0	192.053
9	188	-0.11141	23.2	93	4.12818	2157.6	383.921
9	202	0.32864	19.6	95	1.45059	1862.0	137.806
9	216	0.03496	15.2	95	7.80011	1444.0	741.010
10	167	0.01395	6.4	86	0.32964	550.4	28.349
10	188	-0.08952	13.0	93	2.81689	1209.0	261.971
10	202	0.32628	11.5	78	1.35754	897.0	105.888
10	216	-0.07392	16.6	76	9.44135	1261.6	717.543
12	167	0.02759	8.7	91	8.29340	791.7	754.699
12	188	-0.14714	8.3	88	9.90720	730.4	871.834
12	202	0.31967	9.5	79	8.40176	750.5	663.739
12	216	0.00814	10.8	84	6.46677	907.2	543.209
13	167	0.07536	15.1	80	8.73071	1208.0	698.457
13	188	-0.29752	12.9	67	0.53800	864.3	36.046
13	202	0.30671	13.8	77	9.94588	1062.6	765.833
13	216	-0.27918	18.2	91	9.14480	1656.2	832.177
14	167	0.06354	18.8	95	4.66334	1786.0	443.017
14	188	-0.18513	34.1	97	5.45283	3307.7	528.925
14	202	0.06868	28.5	95	6.02171	2707.5	572.062
15	167	0.04631	7.8	91	4.38227	709.8	398.787
15	188	-0.28585	12.2	86	7.14023	1049.2	614.060
15	202	0.26894	11.2	70	7.24598	784.0	507.219
15	216	0.04408	9.6	70	4.30613	672.0	301.429
17	167	0.00717	4.3	92	8.02007	395.6	737.846
17	188	-0.21325	9.6	95	9.84743	912.0	935.506
17	202	0.36997	8.8	96	7.79588	844.8	748.404
17	216	0.03502	9.9	91	4.93217	900.9	448.827
19	167	0.05935	8.7	94	4.94486	817.8	464.817
19	188	-0.51091	13.7	93	8.20618	1274.1	763.175
19	202	0.52657	11.4	57	6.92027	649.8	394.455
19	216	-0.12377	10.2	53	3.39245	540.6	179.800
20	167	0.03890	13.8	84	6.70455	1159.2	563.182
20	188	-0.28621	14.5	86	8.68418	1247.0	746.839
20	202	0.12908	12.1	97	8.43884	1173.7	818.567
22	167	0.09708	25.2	56	6.43382	1411.2	360.294
22	188	-0.30667	18.9	57	7.65629	1077.3	436.409
22	202	0.37906	13.2	96	6.29423	1267.2	604.246
22	216	-0.13396	9.1	96	3.60395	873.6	345.979
25	168	0.07040	17.6	58	5.05160	1020.8	292.993
25	202	0.23310	11.0	61	5.18075	671.0	316.026

RESULTS FROM 1980 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
25	216	-0.14906	2.9	72	3.32469	208.8	239.378
27	168	0.06318	11.5	77	6.03839	885.5	464.956
27	203	0.01240	2.7	67	4.19999	180.9	281.399
27	217	0.26190	2.9	79	3.30239	229.1	260.889
32	168	0.11196	4.3	78	4.55999	335.4	355.679
32	189	0.03383	2.2	58	2.12639	127.6	123.331
32	203	-0.02912	1.6	37	3.91199	59.2	144.744
34	168	0.08109	9.2	87	5.45759	800.4	474.810
34	189	-0.01832	1.8	89	4.35839	160.2	387.897
34	203	0.05440	1.1	93	3.99359	102.3	371.404
34	217	-0.14253	2.2	91	4.36319	200.2	397.050
47	169	0.00650	6.5	90	7.13537	585.0	642.183
47	204	-0.03122	2.3	49	6.50033	112.7	318.516
51	169	-0.03065	4.9	66	7.85861	323.4	518.668
52	169	-0.02305	2.3	76	6.98543	174.8	530.893
52	204	0.00781	1.2	34	6.27101	40.8	213.214
54	169	0.10034	2.5	95	6.53120	237.5	620.464
54	204	-0.00734	1.3	85	3.84551	110.5	326.868
56	169	0.04853	2.1	45	5.06708	94.5	228.019
57	169	0.13723	12.0	98	7.43966	1176.0	729.087
57	204	0.03505	2.7	95	5.55659	256.5	527.876
58	169	0.09069	51.9	78	7.81010	4048.2	609.188
58	190	0.08101	51.3	70	6.69437	3591.0	468.606
58	204	0.23137	1.4	80	5.87852	112.0	470.282
61	170	0.07886	18.0	97	7.76204	1746.0	752.918
61	191	0.01687	16.7	95	9.14948	1586.5	869.201
61	205	0.05334	3.9	89	8.77724	347.1	781.174
62	170	0.12348	7.8	95	4.36958	741.0	415.110
62	191	0.02467	7.6	95	3.60819	722.0	342.778
63	170	0.05902	19.1	97	5.21558	1852.7	505.911
63	191	0.09748	17.4	90	4.66145	1566.0	419.530
63	205	0.04569	3.8	91	3.48975	345.8	317.567
65	170	0.11889	9.0	90	6.29001	810.0	566.101
65	191	-0.26257	9.3	85	8.47691	790.5	720.537
65	205	0.10724	7.1	89	0.16891	631.9	15.033
70	170	0.11523	9.5	84	7.96085	798.0	668.711
70	191	0.02163	7.7	89	7.39826	685.3	658.445
70	205	-0.03556	27.6	98	8.45999	2704.8	829.079
71	170	0.11426	11.8	89	9.25819	1050.2	823.979
71	191	-0.05893	26.0	91	0.51649	2366.0	47.001
71	205	0.27320	27.3	98	7.96301	2675.4	780.375
72	170	0.05388	6.7	94	5.83388	629.8	548.385
72	191	-0.07802	6.9	97	8.17333	669.3	792.813
72	205	0.17925	14.4	97	6.88184	1396.8	667.538
73	170	0.09287	52.4	69	6.50177	3615.6	448.622
73	191	-0.09501	5.8	77	8.18440	446.6	630.199
73	205	0.08234	12.8	82	9.12904	1049.6	748.581
74	167	0.05796	23.0	98	4.99562	2254.0	489.571
74	188	0.03330	18.6	97	4.79681	1804.2	465.291
74	202	-0.07378	9.1	93	5.80355	846.3	539.730
74	216	0.40267	17.8	94	6.64532	1673.2	624.660
80	167	0.12638	19.5	95	0.46050	1852.5	43.747
80	188	-0.00092	19.0	78	8.05705	1482.0	628.450
80	202	0.06196	18.5	78	7.73513	1443.0	603.340
80	216	-0.06256	13.1	92	7.55432	1205.2	694.997
90	169	0.19732	10.6	62	5.95199	657.2	369.023

RESULTS FROM 1980 DATA

SITE	JDATE	K	SURFACE	COVER	PROFILE	ISFCOV	IPRCOV
93	169	0.00373	10.5	73	7.24121	766.5	528.608
93	204	0.09237	6.2	82	6.90605	508.4	566.296
94	169	0.02422	3.6	68	3.92930	244.8	267.192
94	204	0.08994	4.1	62	4.21595	254.2	261.389
98	170	-0.02417	52.2	67	4.40792	3497.4	295.331
98	205	-0.00656	6.7	19	4.60143	127.3	87.427
100	170	-0.07984	13.8	87	7.70102	1200.6	669.989
100	205	-0.03295	16.3	90	7.14383	1467.0	642.945
101	170	-0.12083	20.5	79	0.53493	1619.5	42.259
101	205	0.10829	6.6	79	4.18076	521.4	330.280
102	170	-0.07389	52.9	85	6.14015	4496.5	521.913
102	205	0.13090	6.6	85	6.64937	561.0	565.196
103	170	-0.04701	51.8	84	4.40585	4351.2	370.091
103	205	0.00557	4.7	88	4.83389	413.6	425.382
104	170	0.00466	59.0	91	0.45007	5369.0	40.956
104	205	0.08405	17.7	98	9.64195	1734.6	944.911
105	171	-0.00424	39.8	94	9.69730	3741.2	911.546
105	206	0.38930	27.9	92	7.42796	2566.8	683.372
106	171	0.02286	6.4	92	6.09587	588.8	560.820
106	206	0.08675	11.0	90	6.87077	990.0	618.369
108	167	0.05227	17.0	92	6.61499	1564.0	608.579
108	188	0.09731	7.6	96	5.39342	729.6	517.768
108	202	0.02137	7.7	94	4.63049	723.8	435.266
108	216	0.05724	11.9	93	4.95242	1106.7	460.575
111	169	0.02695	0.9	65	1.15200	58.5	74.880
113	169	-0.00156	50.6	80	3.21599	4048.0	257.279
113	204	0.01585	0.7	88	2.51999	61.6	221.759
114	169	0.02556	10.3	75	4.32098	772.5	324.073
114	204	0.03390	6.7	96	4.78223	643.2	459.094
118	170	-0.03361	3.9	48	7.14015	187.2	342.727
118	205	-0.04181	10.5	84	6.43193	882.0	540.282
119	171	-0.03484	6.7	96	7.28774	643.2	699.623
119	206	0.03204	10.1	99	7.30250	999.9	722.947
120	171	-0.00903	9.7	87	6.14753	843.9	534.835
120	206	0.12900	20.7	88	7.52021	1821.6	661.778